UNIVERSITY OF ALBERTA

THE ASTRAND-RYHMING NOMOGRAM AS A PREDICTOR OF AEROBIC CAPACITY FOR SECONDARY SCHOOL STUDENTS.

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

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by

RODNEY C. HYDE

EDMONTON, Alberta

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "The Astrand-Ryhming Nomogram As A Predictor of Aerobic Capacity for Secondary School Students" submitted by Rodney C. Hyde in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

The purpose of the study was to investigate the validity of the Astrand-Ryhming nomogram for males and females of secondary school age by comparing values obtained from the Astrand-Ryhming "predicted" maximal oxygen intake test with those of the Astrand "actual" maximal oxygen intake test. The secondary purposes were to determine regression lines between the actual and predicted values, to investigate sex differences with respect to work capacity, to compare the work capacity of Alberta secondary school students with that of Europeans and Americans of a similar age, and to investigate the work capacity changes during the summer vacation.

The study was composed of two separate investigations designated as Experiments I and II. In Experiment I maximal oxygen consumption was measured by both the Astrand-Ryhming predicted and the Astrand actual methods for 29 males and 27 females of secondary school age. In Experiment II the maximal oxygen consumption of 500 males and 417 females who were considered to be representative of the secondary school population of Alberta was measured by the Astrand-Ryhming predicted maximal oxygen intake test.

The difference between the actual and predicted maximal oxygen consumption values in Experiment I were analyzed under three conditions for each sex, i.e., the predicted values were taken from (I) a separate submaximal test,(II) the first work level of the actual test and (III) the second of the two tests.

Within the limitations of the study the following conclusions were made. The Astrand-Ryhming nomogram predicted mean maximal oxygen consumption values equivalent to those obtained on the Astrand actual test for females of secondary school age. The predicted test underestimated the male values. The correction factor should be employed with this age group. The Astrand-Ryhming predicted test appears to differentiate between individuals who are in widely different states of training but not between individuals who are in approximately the same state of training. The mean aerobic capacity of males is superior to that of females for all age groups. Alberta students may have inferior work capacities as compared to Swedish children of the same age but Alberta children compare favourably with children of other areas of the same age. The aerobic capacity of females decreases significantly over the summer vacation while that of males shows no change. There is a need to study in detail, the variables which affect the predicted maximal oxygen intake value.

ACKNOWLEDGMENT

"Nothing will ever be attempted if all possible objections must first be overcome."

Samuel Johnson.

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

Frequently we are told that Canadians are unfit and that each individual should pay more attention to his own personal "physical fitness". While there is much conjecture about this entity we have no readily accessible method of determining it (42:44). We are even unable to agree on a definition of "physical fitness". Johnson has stated (48 cited in 12:323):

> Quantitative assessment of physical fitness is one of the most complex and controversial problems in applied physiology. This situation arises in part from lack of general agreement on what constitutes fitness for withstanding various types of stress and in part from lack of agreement on what measures allow valid comparisons to be made among different individuals exposed to the same stress.

Physical fitness can be defined in many ways (12,25, 29,41,59,60). It is readily evident from the great diversity of definitions that there is more than one type of fitness (37,42) and that fitness may be specific (44).

The present study is limited to one aspect of fitness, - the ability of the individual to perform prolonged physical work (59,62).

Åstrand and Ryhming (15) have developed a submaximal bicycle ergometer test from which the maximal oxygen intake (aerobic capacity) of an individual can be estimated from a nomogram. From this estimation, the work capacity of the

individual can be evaluated. The test is simple, quick and relatively easy to administer so that large numbers of subjects can be tested in a relatively short time.

The Problem

If the Astrand-Ryhming nomogram is to have practical application, it is essential that the predicted maximal oxygen consumption values be close to those which are actually determined through a maximal test.

The purpose of this study is to investigate the validity of the Astrand-Ryhming nomogram for males and females of secondary school age, by comparing values obtained from the Astrand-Ryhming "predicted" maximal oxygen intake test with those of the Astrand "actual" maximal oxygen intake test.

Subsidiary Problems. The following subsidiary problems will be investigated:

1. Regression lines will be established in an attempt to further minimize differences between the predicted and actual maximal oxygen intake values.

2. Sex differences will be analyzed in a sample of secondary school students, with respect to work capacity as measured by the Astrand Ryhming predicted maximal oxygen intake test.

3. The work capacity of Alberta secondary school children will be compared with that of European and American children of a similar age.

4. Work capacity changes over the summer vacation will be evaluated.

In the main problem the null hypothesis asserts there will be no significant difference between the means of the Astrand actual and the Astrand-Ryhming predicted maximal oxygen intake tests. The alternate hypothesis asserts that there will be a significant difference between the means.

$$H_o: u_1 = u_2 \qquad H_1: u_1 \neq u_2$$

The null hypothesis of the second subsidiary problem asserts that the means of the aerobic work capacities of the two sexes will not be significantly different. The alternate hypothesis asserts that the mean of the aerobic work capacity of male subjects will be significantly greater than the mean of the aerobic work capacity of female subjects.

$$H_o: u_1 = u_2 \qquad H_1: u_1 > u_2$$

Justification of the Study

The stress on fitness due to increased publicity and public awareness makes it imperative that we have information on the topic, and norms available, so that valid comparisons and evaluations can be made. The secondary school population appears to be a logical starting point.

Astrand (12) states that in the clinic it is of value to know the normal range of different bodily functions and in industry to know the capacity for physical work of the human being. Military forces need to train men in as short a time as possible to a high standard of work capacity, and to group them according to this capacity. In sports, physiological bases are necessary for the planning of rational

training and practice, and for a sound choice of events with regard to the participants' sex and age.

Andersen (3) feels that it is time to start more intensive studies of the physical fitness of average men and women in order to evaluate age and sex differences and differences due to various types of occupations. There is a need for incorporation of all factors which may influence the physical working capacity, e.g., smoking, diet, etc. Andersen states a number of the questions which need to be answered: such as, what is the optimal physiological capacity for the average man in our own society and how much, and what type of exercise should be recommended? Andersen personally feels that the ultimate answer to these questions will come only when a sufficient amount of knowledge is accumulated on man's physiological capacity and when the factors which limit that capacity are known.

The methods normally employed to evaluate work capacity are time-consuming, require extensive equipment and require the subject to work to near-exhaustion. Because of the attendant difficulties in such extensive tests, there is a need for a valid submaximal test, requiring a minimum of equipment, by which a large number of subjects can be tested in a short time, and requiring little motivation on the part of the subject. This study will evaluate the Astrand-Ryhming predicted maximal oxygen intake test in these terms.

The investigation as to the validity of the Astrand nomogram for the population to be studied, is obvious since

the nomogram was based on data obtained from Swedish subjects age 18 to 30 (15).

Sex differences with respect to work capacity need to be ascertained since relatively few studies of this nature have been reported (2,11,12,13,14,20,26,27,28,55,62). Few of these studies have considered aerobic capacity. As a result there is not comparable data as to how the sexes differ in response for work of a given intensity (55). Though most previous studies have indicated that the working capacity of women is inferior to that of men after the age of puberty, it is necessary to determine if comparable differences exist in the Alberta secondary school population and if so, to what extent. If the difference (assuming there is a difference) seems extraordinary as compared to what has been reported in the literature perhaps this would call for an evaluation of the adequacy of the physical education programmes in the school.

P-O. Astrand (11), though he states that women are the "weaker sex" since they do not have the same capacity for prolonged strenuous work as men, reports that there is no reason why forms of athletics requiring endurance should be harmful to women. He also suggests that from a physiological point of view females can participate in the same sports as males. It is feasible that the extent to which women should be allowed to participate in these activities can be assessed by comparing males and females by means of a number of parameters, one of which is aerobic capacity.

So that the fitness of Canadians can be evaluated it is logical that we make comparisons in work capacity with a similar sample in countries in which the population is considered to be "more fit" than the Canadian population. The Scandanavian countries, and especially the Swedish people, stand out as leaders in fitness and seem to be a logical group with which to make comparisons.

Little work has been reported on the loss of fitness during the severe winter months of this area (28). Though this segment of the study will include a test-retest situation in the spring and the fall rather than in the fall and spring certain implications may be drawn from the results of this study. If there is a gain in work capacity over the summer months there may conversely be a loss in fitness over the winter months. If this proves to be the case, perhaps physical education programs should take this factor into consideration.

Limitations of the Study

1. The sample to be studied is limited to a segment (approx. 900 subjects) of the Alberta Secondary school population. General conclusions are limited as to the applicability of this sample to the whole population.

2. The study is further limited by the applicability of the use of a bicycle ergometer with the Alberta population. The subjects were not orientated to the test.

3. Only one aspect of fitness will be studied, that is cardio-respiratory fitness. This is measured by the ability

of the subject to perform prolonged physical work.

4. Only the parameters stated in the problem and the subsidiary problems are considered.

5. The statistical procedures used to analyze the data further limit the study.

The following basic assumption has been made:

1. The nomogram does not allow for the prediction of very low maximal oxygen intakes, i.e., predictions from high heart rates at low work loads. The nomogram has been extended proportionately to allow for the prediction of these low values.

<u>Definition of Terms</u>.

<u>Kilopond Meter (Kpm)</u>. One kilopond is the force acting on the mass of one kilogram at normal acceleration of gravity (14).

<u>Physical Work Capacity</u>. Physical work capacity is the individual's total ability to perform prolonged physical work. This means the ability of the cardiopulmonary system to take up, transport, and give off oxygen to the muscle tissues for the performance of physical work (61).

<u>Steady State</u>. The steady state occurs when the individual's organic functions have adapted to the work being performed. At this time oxygen intake is equal to oxygen expenditure. For the purpose of this experiment, if the difference between the pulse rate readings taken at the end of the fifth and sixth minutes of exercise did not differ by more than $\pm$ 5 beats, the subject is said to have reached a steady state.

If the readings obtained at this time differed by more than $\pm$ 5 beats the exercise was continued until this criterion was met.

Maximal Oxygen Intake. The maximal oxygen intake is the rate of oxygen consumption attained when the cardio-respiratory mechanisms can make no further adjustments to increasing work loads, i.e., oxygen intake remains constant even if the work load be increased. In the Astrand maximal oxygen intake test, if the oxygen consumption at two consecutive work loads decreases or differs by less than 80 ml., the subject is considered to have reached his maximal oxygen intake. The maximal oxygen intake is also known as the aerobic capacity.

Maximal. The term maximal must be used with caution. Maximal values for oxygen consumption should be characterized as being "the highest attained values and possibly maximum." (11:16) Thus if an individual appeared to have reached the criterion for maximal oxygen consumption and then improved his performance when subjected to an additional workload, this latter value was considered to the maximum for that individual. Similarly, if a subject was unable to complete a test session due to fatigue before reaching the criterion for maximal oxygen intake, his highest attained value was considered to be his maximum.

Random Sample. A random sample is an unbiased cross-section of a larger group or population. This study actually employed a stratified random sample drawn by the Dominion Bureau of Statistics, based on a geographical, social and

economical representation of the province of Alberta (40). However, the random sample technique was applied in the individual schools.

CHAPTER II

REVIEW OF THE LITERATURE

Literature Pertaining to Aerobic Capacity as a Measure of Fitness. While it is evident that cardio-respiratory fitness is only one part of fitness, it is considered to be an important aspect (42).

Taylor (69:126) stated that since all physical activity is eventually paid for by the utilization of foodstuffs, the relationship between oxygen consumption and physical activity is of the first importance in the understanding of physical activity. In the same trend, P.-O. Astrand and Saltin (17) pointed out that a measurement of the maximal oxygen uptake (aerobic work capacity) of a subject when performing muscular exercise gives the maximal rate of energy output by combustion within the body.

Mitchell, et al (56) have noted that the maximal oxygen intake which a normal subject can achieve is sometimes taken as an index of maximal cardiovascular function when the pulmonary fucntion is normal. They felt the test (maximal oxygen intake test) might become of enormous value in the critical evaluation of normal and abnormal cardiovascular function if the concept is sound.

According to Astrand and Ryhming (14) the limiting factor for the maximal oxygen intake (aerobic capacity) in types of work which engage large groups of muscles is probably the capacity and the regulation of the oxygen-transporting system.

Taylor, et al (69) asserted that the maximal oxygen

intake appeared to offer the possibility of determining with precision one of the limiting factors in endurance performance characterised by a high level of energy expenditure.

Various authors consider maximal oxygen intake or aerobic capacity to be the best measure of cardio-respiratory fitness, (12,42,58,61,70).

P.-O. Astrand (12), in an excellent article on human physical fitness, considered aerobic capacity to probably be the best measure of a person's physical endurance.

Maximal oxygen intake was considered by Taylor, et al (70) to be the most effective measure of the capacity to perform aerobic work.

Newton (58) stated that the maximal rate at which oxygen can be consumed is an important measure of the ability of the circulatory and the respiratory systems to meet the demands placed on them by strenous physical activity. Maximal oxygen intake is not only the best physiological indicator of the capacity of a man for sustaining hard work, it is also the most objective measure by which one gains insight into the physical fitness of an individual as reflected by his cardiovascular system.

Rodahl, et al (61) simply noted maximal oxygen intake as the best indicator of physical work capacity. However in Muscle as a Tissue (62) Rodahl and Issekutz limited this statement to some extent by asserting that the aerobic work capacity is the best measure of an individual's physical

fitness but only provided the definition of physical fitness is restricted to the capacity of the individual for prolonged heavy work.

Hettinger, et al (42) agreed that maximal oxygen intake is probably the best measure of physical fitness but the method used to obtain the figure is time-consuming, requires fairly complicated laboratory procedures and demands a high degree of cooperation from the subject.

Literature Pertaining to the Prediction of Maximal Work Capacity from Submaximal Work. The need for a simple work capacity test based on observation during submaximal work stress has long been recognized (42). Little work has been produced in this area though it is essential to have a simple test available, since extensive equipment, and the time factor limit the use of maximal tests. Four recent tests have been presented. In 1954, Astrand and Ryhming (15) introduced a nomogram from which maximal oxygen intake could be predicted from a steady state pulse rate at a known work load. This procedure has been referred to above as the Astrand-Ryhming predicted maximal oxygen intake test. In 1958 Asmussen and Hemmingsen (5) presented a curve and a formula from which maximum extra oxygen intake could be determined from measurements made during submaximal work. Extra oxygen intake is the increase in oxygen-uptake above the resting value. Issekutz (46) predicted maximal oxygen uptake from the respiratory quotient taken at submaximal levels and reported a difference of only 5 percent between

the estimated and actual values.

Workman and Armstrong (73) developed an equation to predict oxygen consumption while walking on the treadmill, which, readily lent itself to nomographic presentation. The prediction was made in terms of height, weight, teadmill speed and grade.

Literature Pertaining to the Astrand Nomogram. Astrand and Ryhming (15) first introduced the nomogram in 1954 as stated above. The nomogram was based on data obtained from well-trained male and female Swedes age 18-30. In 1960 Irma Astrand (6) presented a nomogram adjusted for a difference in mechanical efficiency at low work loads since the difference in efficiency introduced a relatively large error if it were not taken into account. The use of lower work loads is necessary, especially for older individuals, and therefore the nomogram was adjusted on this point. At the same time correction factors for age were introduced.

Irma Astrand (6) stated at this time three prerequisites for the use of the predictive procedure. They are as follows:

1) the pulse rate during submaximal work increases approximately rectilinearly with the oxygen intake,

2) submaximal pulse rates not lower than 125 beats per minute are used for the prediction and

3) the pulse rate of the subject can reach a maximal value of about 195 beats per minute (S. D. ± 10) when cycling or walking.

According to Rowell, <u>et al</u> (63:919), the nomogram can be reconstructed in the following manner. They state:

> If the VO_2 to pulse rate slope is originated at 60 beats/min. and zero VO_2 and then extrapolated through a single value for submaximal VO_2 and pulse rate to a pulse rate of 195 beats/min., the VO_2 at the latter point corresponds exactly to that read from the nomogram as predicted max. VO_2. The pulse rate at 50% of this predicted max. VO_2 will always be 128 beats/min.

<u>Literature Pertaining to the Criteria of the Pre-requisites to the Age Group Being Studied</u>. In order for the nomogram to predict a valid value of maximal oxygen intake the three criteria mentioned above must be met. Since the nomogram was based on figures obtained from an age group older than the sample to be tested in this experiment, it is necessary to ascertain whether or not a younger age group could meet pre-requisites (1) and (3). Since condition (2) is a matter of experimental procedure it will not be discussed further.

<u>Pulse Rate and Oxygen Consumption</u>: As will be seen later it is generally accepted that the pulse rate increases approximately rectilinearly with oxygen consumption.

Bengtsson (20) reported that for subjects age 5 to 40 the heart-rate increased linearly with exercise intensity. At the same time oxygen consumption showed the same relation - ship with exercise intensity.

P.-O. Astrand (11) found a linear relationship for subjects age 4 to 33.

This topic is discussed below in more detail.

Pulse Rates of a Maximal Value of 195 Beats Per Minute:

I. Astrand (6) found it necessary to introduce a correction factor for older subjects since they were able to attain heart rates of only approximately 160 beats per minute. As a result the values predicted from the nomogram were considerably higher than those found by actual measurement. However a number of studies have shown that young people can reach high heart rates (11,21,29,31,32,60).

In 1938 Robinson (60) reported a classical study on treadmill performance. Eleven boys whose mean age was 14.1 years reach pulse rate means of 195 beats per minute after a 5 minute run on the treadmill. In the same report he cited 2 other studies. Twenty-seven boys age 13-19 reached mean heart rates of 190 beats per minute while running up and down stairs after running 100 feet on the level (21). Also, school boys age 12-19, reached average heart rates of 195 beats per minute (32).

P.-O. Astrand (11) noted maximal heart rates of between 202 and 211 beats for subjects up to age 20 while adult subjects averaged around 195 beats per minute.

In 1963 Cumming and Cumming (27) reported that Winnipeg children age 6 to 16 maintained pulse rates from 190 to 200 beats per minute without indicating any undue discomfort. In a later study completed by Cumming and Danzinger (28), in only 4 of 49 subjects age 10 to 11 was the pulse rate unable to reach 200 beats per minute.

Morse, et al. (57) found that for 110 boys age 10 - 17 years the maximal heart rates varied little with age from the overall average of 196 beats per minute.

Literature Pertaining to the Accuracy of Prediction from the Nomogram. When Astrand and Ryhming first presented the nomogram they stated (15:221):

> . . . the nomogram is based on results from experiments with healthy subjects 18 to 30 years of age. We do not know its validity when testing younger or older people or patients with diseases in the oxygen-transporting system. Therefore results obtained from tests with those categories must be evaluated with special criticism. Experience combined with further research should decide upon the application of the nomogram and interpretation of results.

It should be emphasized that the nomogram gives only a prediction of work capacity and not an exact value. In 1960 Irma Astrand pointed out (6:59):

> It should be strongly emphasized here that this method of measuring only the submaximal oxygen intake or work load and heart rate will always be only an aid for a rough prediction of the aerobic work capacity. If one wishes to obtain more exact information, it is necessary to measure the aerobic work capacity directly.

When Astrand and Ryhming (15) compared actual and predicted maximal oxygen intake values they found that for males working at 1200 kpm. and females at 900 kpm., for 2/3 of the cases the difference was less than 6.7 per cent for men and 9.4 per cent for women. For lower work levels the differences reported were 10.4 per cent and 14.4 per cent for males and females respectively.

For well-trained individuals I. Astrand (6) reported

the standard deviation of the predicted maximal oxygen intake from the actual measurement was about $\pm$ 10 per cent while for a normal population the deviation was $\pm$ 15 per cent. It was also noted that the accuracy was somewhat higher when using relatively higher work loads. For 66 males age 50 - 59 years the standard deviation was $\pm$ 10 per cent with a correlation coefficient of 0.709 and $P < 0.001$ when the age factor is used. In a previous study in 1958, I. Astrand (16) reported predicted values for maximal oxygen consumption which were much higher than those obtained experimentally. She felt the difference was caused by low maximal heart rates of older subjects and it was due to this that the correction factor for age was introduced.

In 1965 P.-O. Astrand (14) introduced a correction factor for subjects of 15 years of age. This factor appears to have resulted from the high maximal heart rates attained by young subjects.

Larsson, et al (52) compared the work capacity of six diabetic boys interested in sports with six non-diabetic boys of the same age and interests as the diabetics. The measured values for the maximal oxygen uptake were on the average 0.2 litres per min. higher than the values calculated from the Astrand-Ryhming nomogram. The calculated values were 7.9 per cent lower, but this difference was not significant. They concluded that the agreement between the measured oxygen capacity and that calculated from the heart rate, demonstrated that the Astrand-Ryhming nomogram was applicable to adoles-

cents, diabetics, and non-diabetics, as well as the 20 to 30 year old subjects for whom it was originally constructed. Nor, they concluded, was a correction factor necessary for the adolescent age group as for the individual above 30 years of age.

de Vries and Klafs (30) determined correlations and predictive errors involved in predicting maximal oxygen consumption from six submaximal tests of working capacity. The Astrand-Ryhming nomogram had correlation coefficients of 0.736 with a standard error of ± 0.395 l/min. when compared to the maximal test. When body weight was divided out the correlation coefficient dropped to 0.522. The authors concluded that of the 6 tests the highest predictive values were realized from the Astrand-Ryhming nomogram and the Sjostrand work capacity test. This study involved sixteen physical education major students, 20-26 years of age. This group would resemble closely the subjects used by Astrand and Ryhming when they constructed the original nomogram.

A significant difference between predicted and actual maximal oxygen consumption (2.26 and 2.38 l/min.) was reported by Hettinger et al (42) in an experiment using 28 policemen 20-30 years of age. The correlation coefficient between the two measures was significant at the 0.01 level of confidence but an actual figure was not presented. However, Rodahl and Issekutz (62) noted a correlation coefficient of 0.47 for a sample which fits exactly the description of Hettinger's

policemen. Rodahl and Issekutz also commented on a further study in which particular effort was made to ensure that the subjects reached their maximal oxygen intake. For 9 policemen the predicted value was only 4.8 per cent greater than the actual value. In two other studies which are briefly mentioned, the difference between the actual and predicted values for 22 untrained men showed a difference of 1 per cent, while for 9 YMCA trained men age 55-68 the difference was 3 per cent.

Borg and Dahlstrom (23) examined the reliability and validity of the nomogram, for a number of men undergoing military training. Values were predicted at both the 600 and 900 kpm work levels in 2 experiments conducted 8 months apart, while validity was measured against the results of a 20 mile ski race. The results of 2 tests at 900 kpm and the results of the ski race showed correlations of 0.38 and 0.45. There was no difference in estimated maximal oxygen intake values when measured at the 600 and 900 kpm levels.

Using 48 physically active adult males Baycroft (18) found that the Astrand-Ryhming predicted test produced correlations of 0.62 with the Astrand actual maximal oxygen intake test and 0.67 with the Mitchell, Sproule and Chapman maximal oxygen intake test. The two actual tests produced a correlation of 0.51. When body weight was partialled out the correlations were 0.53, 0.47 and 0.39 respectively. For physical fitness as measured by the Johnson, Brouha and Darling test of Physical Fitness, the nomogram predicted

physical fitness as well as the Astrand maximal oxygen test and significantly better than the Mitchell, Sproule and Chapman test.

Glassford (39), studying 24 healthy, physically active males, obtained maximal oxygen intake values from the Astrand-Ryhming predicted test, the Mitchell, Sproule and Chapman test and the Taylor, Buskirk and Henchel maximal test. The values in litres per minute obtained on the Astrand-Ryhming predicted test correlated 0.80 with the Johnson, Brouha, and Darling test of Physical Fitness, 0.78 with the Mitchell, Sproule and Chapman test, 0.72 with the Taylor, Buskirk and Henchel test and 0.65 with the Astrand actual test. With body weight partialled out, the resulting correlations were of the same magnitude. The relationship between the nomogram values and any one set of values determined by a direct technique was as good as the relationship between the values of any two direct measures examined in the study.

Rowell, et al (63) criticized the use of heart rates at submaximal work since pulse rate can vary independently of the oxygen uptake but directly with the emotional state or degree of excitement, as well as the degree of physical conditioning, elapsed time after the previous meal, total circulating hemoglobin, the degree of hydration of the subject, alterations in the ambient temperature and hydrostatically induced changes from prolonged erect posture. They found that the predicted maximal oxygen intake underestimated the actual

maximal oxygen intake by 26.8 ± 7.2 per cent and 13.7 per cent in a sedentary group, before and after 2½-3 months of physical training, and by 5.6 ± 4 per cent in a group of ten endurance athletes. For the seven sedentary subjects the predicted maximal oxygen intake underestimated the observed value by 0.82 litres per minute.

In their discussion they emphasized the detrimental effect of emotion on prediction but they concluded that the nomogram provided a reasonably accurate prediction among endurance athletes. This agreed with Astrand's and Ryhming's findings in well-trained subjects.

In 1959 Wyndham and his co-workers (74) questioned the validity of the nomogram. According to their experiments the nomogram underestimated the maximal oxygen intake by 0.32 ± 0.14 l/min. since they found the pulse rate-oxygen consumption curve to deviate toward oxygen consumption at higher pulse rates, i.e., at these higher levels the relationship is no longer linear but becomes asymptotic. If this is the case, there would be an underestimation of predicted oxygen intake values. Irma Astrand (6) answered this criticism by pointing out that it was not the premise of the nomogram to assume that the heart rate is a linear function of oxygen uptake throughout the entire range of values. The nomogram was constructed empirically from data on heart rate and oxygen uptake during submaximal work and the maximal oxygen uptake reached a well established level. According to Astrand it was not analyzed whether or not the heart rate

increased with the oxygen uptake at upper levels. She then called attention to the fact that the asymptotic curve described by Wyndham et al had previously been observed in subjects suffering from slight hypoxia (6). The Wyndham study may have been conducted at 5,500 feet above sea level and therefore conditions were not normal although one of the necessary conditions for the use of the nomogram is a normal environment. The hypoxic hypothesis is further strengthened by the fact that the heart rates reported by Wyndham were unusually low for young subjects.

Rowell, et al (63) also criticized Wyndham, et al. The former stated that contrary to the latter's conclusions the nomogram should overestimate the true maximal oxygen intake since they show in their graphs pulse rates at 50 per cent of maximal oxygen consumption as being less than 128 beats per minute.

Literature Pertaining to the Relationship Between Pulse Rate and Oxygen Consumption. As noted above one of the essential pre-requisites for the use of the estimation procedure is the approximately linear relationship between pulse rate and oxygen uptake during submaximal work. Some investigators simply cite the fact that there is a relationship (5,62,70,72) while several others actually show experimental evidence.

P.-O. Astrand (12) stated that the slope of the heart rate-oxygen intake curve is determined by the subject's aerobic capacity and later he said that it is evident it is

impossible to judge a person's physical condition from the slope and the mean of a curve showing heart rate if the aerobic capacity is not taken into consideration (11). He also explained that the physiological explanation for the observation of a high correlation between heart rate when performing submaximal work and the maximal oxygen intake was far from obvious (12).

Boothby (22) used himself as a subject and discovered the pulse rate during work on a bicycle ergometer was a linear function of metabolism as measured by oxygen consumption. Krogh and Lindhard (51) utilized the data reported by Boothby, that reported by Benedict and Cathcart (19), as well as data compiled from 21 other subjects who they tested themselves. For the whole material there was an approximate linear relationship between pulse rate and oxygen consumption as the two quantities increase. However, single determinations showed rather wide deviations and the rate of increase for an individual may or may not be the same as that for another individual. They concluded that when other influences are absent the pulse rate is a linear function of the metabolism independent of the kind of muscular work performed, but there appeared to be a variation between individuals.

In 1942 Dill (31) reported a linear relationship for 2 subjects when heart rate was plotted against oxygen used.

P.-O. Astrand (11) plotted heart rate against oxygen consumption for both male and female subjects. For male

subjects the average heart rate value increased linearly with the oxygen intake from 128 beats per minute at 2.1 litres per minute oxygen consumption to 167 beats per minute at 3.3 litres per minute consumption. Female values also increased linearly but for a given oxygen consumption the female pulse rates were much higher.

P.-O. Astrand, et al (8) found that for one well-trained subject heart rate increased linearly with oxygen uptake after 100 beats per minute.

For 44 females age 20-65, I. Astrand (6) found an approximate rectilinear relationship in all age groups.

In 1958 Asmussen and Hemmingsen (5) presented curves which showed a practically linear relationship between heart rate and oxygen uptake during arm-work as well as leg-work but the slope of the curve for arm-work was always steeper than for leg-work, i.e., there was a lower oxygen intake in the arm-work for a given heart rate.

Anderson and Hart (4), using Eskimos as subjects, noted a linear correlation between heart rate and oxygen consumption up to maximum levels during steady state exercise.

As mentioned above, Wyndham, et al (74) criticized the pre-requisite for the nomogram that pulse rate and oxygen consumption are rectilinearly related. The curves they produced were linear up to a point near the maximum value of heart rate but near the maximum value there was a sharp deviation of the curves towards oxygen intake values higher than would be obtained if the linear parts of the curves

were extrapolated until they intersected maximal heart rate values. These curves are shown below. This criticism was answered by I. Astrand (6), and Rowell, et al (63) and has already been discussed.

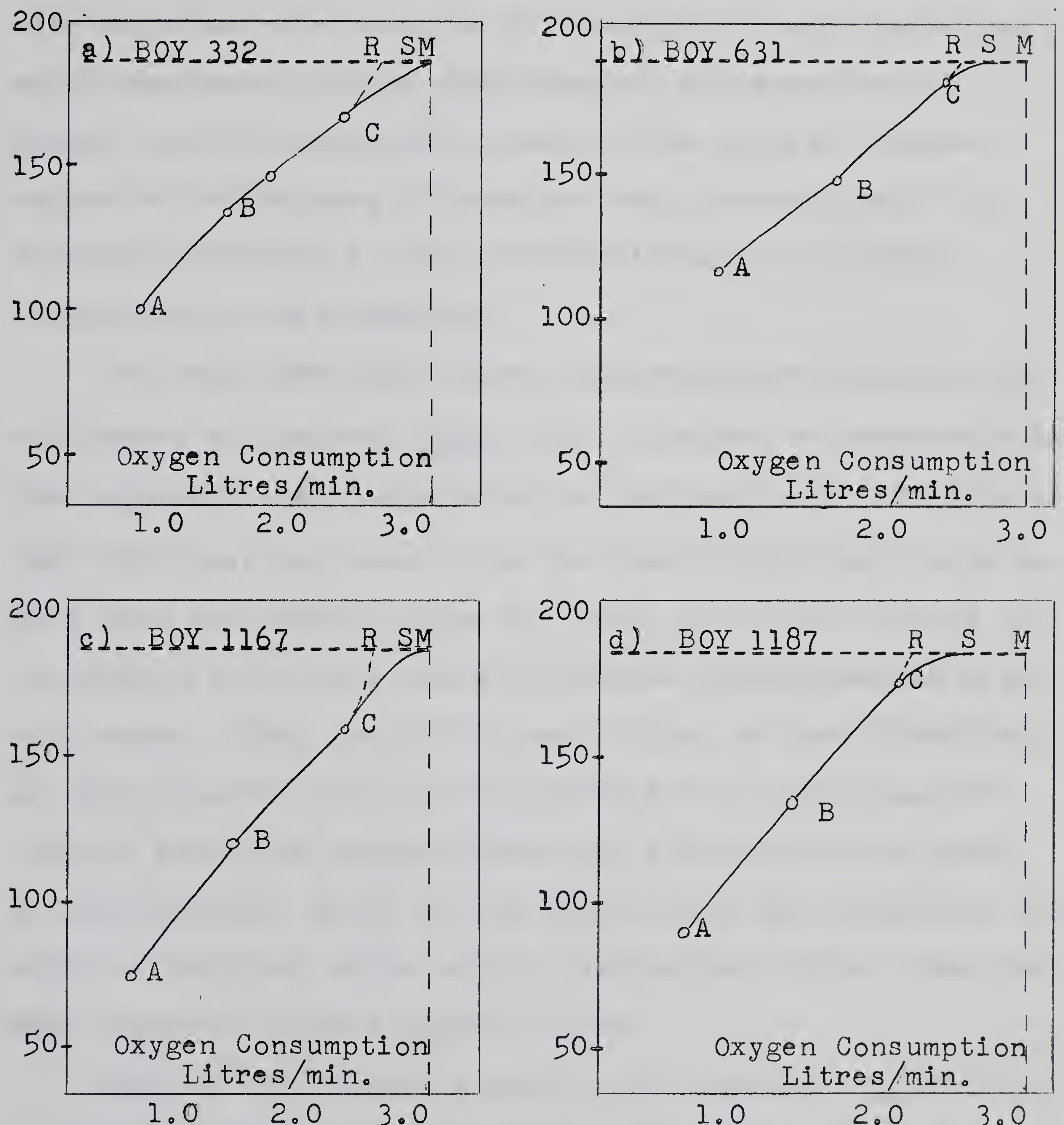

FIGURE II-i. Curves fitted to heart rate and O_2 intake values. These curves show a bias towards O_2 intake values higher than would be indicated by extrapolation of straight line to maximum heart rate values (74).

During treadmill running Astrand (11) noted that oxygen intake per kg. body weight increased linearly with the speed of the treadmill.

Taylor, <u>et al</u> (70) have noted that the slope of the work rate vs pulse rate curve is different for every individual and furthermore certain physiological and experimental errors such as temperature, meals, time of day, fatigue, mechanical efficiency of work and test protocol tend to displace the curve to the left resulting in an underestimation of work capacity.

The heart rate and oxygen consumption relationship is considered by Wyndham, <u>et al</u> (74) to depend on whether or not they approach their asymptotes at the same rate. They declare that this does not seem to be the case. Both heart rate vs. work load and oxygen intake vs. work load curves appear to be linear at low work rates but become exponential at high-work rates. They feel the curves fitted to heart rate data at various work levels are acceptable but in the case of maximum levels of oxygen intake the position is not quite so satisfactory, since in the latter case the asymptotes from which a predicted value can be obtained are higher than the mean measured maximal oxygen intake.

Wahlund (72) agrees somewhat with Wyndham, <u>et al</u> (74) in that he reports the literature as revealing that the linear relationship of pulse rate and oxygen consumption or work - load has not always been found correct at heavier loads. In his own data there was a smaller increase in pulse

rates when work load was increased from 900 to 1200 kg-m/min., than when it was increased from 600 to 900 kg.-m/min. However, he felt this did not disagree with the linear relationship. In order to examine the concept more closely Wahlund attempted to estimate pulse rate values at 1200 kg-m/min. from actual data obtained at 600 and 900 kg-m/min. on the assumption that pulse rate is a linear function of work load. From these results he concluded that a linear relationship exists when the estimated values fall between 155 and 175 beats per minute. He described the pulse rate curves as being inclined below this range and declined when they are above it. He then showed that generally speaking no differences exist in using work load instead of oxygen consumption when considering the relationship with pulse rate.

Literature Pertaining to Mechanical Efficiency.

P.-O. Astrand (12) stated that if oxygen intake is to be regarded as an important factor in determining fitness for endurance work, the mechanical efficiency, technique or skill must be regarded as a decisive factor. Taylor (49) claimed mechanical efficiency is the most precise method of expressing the ability to perform a test with economy of energy expenditure.

Mechanical efficiency (M. E.) is calculated by the formula (11):

$$\text{M.E.} = \frac{\text{Work performed}}{\text{Total energy-Basal energy}} \times 100\%$$

In simple movements where large muscle groups are working it has been found that mechanical efficiency shows only small individual variations since during work on the bicycle ergometer the standard variation in mechanical efficiency was $\pm$ 8 per cent of the found value for athletes, normal healthy men, and individuals with heart or respiratory troubles, provided the work level was adapted to the capacity of the individual. However, the more complicated the exercise, the greater are the individual variations in mechanical efficiency.

P.-O. Astrand (11) calculated mechanical efficiencies of 22.5 and 23.4 per cent for males and females respectively at work intensities corresponding to about 50 per cent of the subject's aerobic capacity. He considered these to be close to maximal values.

Dill (31) stated that mechanical efficiency of the body as a whole does not vary much with age. On the other hand Robinson (60) claimed that boys under age 13 have a lower mechanical efficiency than older people at the point where steady state is reached.

For older women, I. Astrand (6) found a significantly lower mechanical efficiency as compared to younger women. She calculated a mechanical efficiency of 22-23 per cent for older men which is the same as reported for younger people (7). Figures obtained from work by 9 older men agreed with this last figure (9).

Taylor, _et al_ (68) found a gross mechanical efficiency

of 12.9 per cent for boys 7 to 15 years of age. When net efficiency was calculated, firstly after deducting for basal metabolism and secondly after deducting energy expenditure sitting quietly in a chair, values of 17.9 and 23.7 per cent were obtained.

Obese individuals were found to have a significantly lower mechanical efficiency than a normal control group (10). Astrand, et al (10) concluded that the actual energy production should be measured and not predicted for obese individuals since there are large individual variations in the oxygen intake of these people.

Mean net efficiency at heavier work loads was found to be significantly less at heavier than at lighter work loads for nine subjects.

Taylor, et al (70) pointed out that there was ample evidence that repeated bouts of work can result in a substantial change in mechanical efficiency, i.e. there is a learning factor. They explained that in areas where bicycles are used by large fractions of the population the difference in the oxygen requirement for weight is small between individuals, but, they cautioned, it is not clear if this will be the case in areas where bicycle riding is not so popular. Astrand (12) appeared to support this premise when he stated that mechanical efficiency can increase with training. However, Rodahl, et al (61) reported no statistically significant difference between the mechanical efficiency of 19 Stockholm boys as compared to 18 Philadelphia boys 14 years of age.

Literature Pertaining to the Steady State. In testing circulatory-respiratory fitness the duration of work must be long enough to permit the adjustment of circulation and ventilation to the exercise, and the determinations have to be performed particularly during the later phases of adaptation (11). The Astrand predictive test assums that this adaptive or steady state can be attained after approximately six minutes' work.

In the first 2 to 3 minutes of work there is a rapid increase in pulmonary ventilation, however the pulse rate and oxygen consumption usually reach a plateau between the third and fifth minutes of work (62).

For older males (50 to 64 years of age), I. Astrand (7) reported that the heart rate usually reached a steady state after 5 minutes' work.

Astrand and Saltin (17) concluded that when respiratory and circulatory functions are measured during lighter muscular exercise the work should last at least 5 minutes since it may take this time for adaptation to occur. They explained that a steady state can be attained in one minute only with extremely heavy exercise.

For work requiring an oxygen intake of 2.00 to 2.22 l/min. the heart rate reached a steady level after 5 to 10 minutes and then remained at this level for 1 to 2 hours of work in experiments conducted by Wyndham, et al (74).

Craig Taylor (66) stated that heart rate did not reach an absolute steady state in his study but rather it had a tendency toward a slow upward drift.

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When a man undertakes a steady rate of work which can be maintained for a long period Taylor (49) noted that the oxygen consumption is characterized by a period of increasing oxygen consumption which continues for approximately 3 to 5 minutes followed by a constant rate of oxygen consumption.

Literature Pertaining to Sex Differences in Working Capacity. The paucity of literature in this area indicates the need for further research.

In 1942 Methany, *et al* (42) reported that on an all-out run on a treadmill, women performed only one half as much work as men before they became exhausted and that men had higher oxygen consumptions in ml/kg/min. although the maximal heart rates were similar. When compared to the ten least fit men the women were not inferior in performance.

P.-O. Astrand (11) found that the increase in maximal oxygen consumption is linear for males and females up to age 13 while after this age the oxygen uptake increases rapidly for men but women tend to decrease. In the age group from 14 to 25 females values are 26 to 29 per cent lower than males values, while in the 12-13 age group the female values are only 6 per cent lower than male values for a corresponding age. When body weight is taken into consideration this difference of 29 per cent is reduced to 17 per cent.

According to Astrand (11) the natural starting point for the relative decreases in the girl's aerobic capacity is the beginning of puberty, and it is a consequence of sexual maturity rather than a question of laziness. He explained

the difference in the following way: at puberty, females receive a relatively large increase in fatty tissue, for this reason it might be better to compare the sexes as to maximal oxygen intake per kg. of body weight. Also, the maximal oxygen intake per unit of hemoglobin is the same for males and females in all age groups except for 10-11 years and sex differences found in oxygen intake per kg body weight are reflected by similar differences in total hemoglobin. It follows that if the total quantity of hemoglobin and the maximal oxygen consumption vary with the muscle mass, the conclusion will be that the female adult ought to have 15 to 20 per cent less muscular tissues per kg body weight than the male adult. The female does in reality show 17 per cent and 20 per cent less maximal oxygen intake and quantity of hemoglobin respectively than the male adult. The smaller aerobic capacity of the female is then explained by this difference in muscular tissue between the male and female.

Other studies have reported results analagous to those of Astrand.

The physical work capacity needed to attain a heart rate of 170 beats per minute (PWC_{170}) was found to be consistently greater for Winnipeg boys than girls, even in the youngest age groups (27).

When Adams, et al (2) plotted surface area against work capacity, the slopes of the regression lines differed for boys and girls age 6 - 14 at the 1 per cent level in favour of the boys. As growth proceeded the difference in work

capacity between the sexes became much greater.

For Swedish school children age 10 - 12 the PWC_{170} of boys was greater than that of girls for both city and country children.

Bengtsson (20) reported slightly different results for Swedish children age 5-13, there being no statistically significant difference between the sexes, though the boys had higher work capacities. At age 15-20 the females had distinctly poorer work capacities than the males while the working capacity of the adult male was 30 per cent superior to that of the female. He also mentions that there are commonly major variations in working capacity during puberty especially in girls and he postulates that this may be due to the fact that the total hemoglobin in relation to body weight increases during puberty in males but is reduced between the age 12 to 20 for females.

Literature Pertaining to the Comparison of Canadian and Foreign Fitness Norms. Little work has been done in this area simply because there have been few fitness studies conducted in Canada which could supply data to allow comparisons with the norms reported in other countries.

In 1963 Cumming and Cumming (27) reported an experiment in which the work load needed to cause an individual's pulse rate to rise to 170 beat/min. (PWC_{170}) was studied. Results showed that Winnipeg boys had mean physical work capacities per square meter of body surface 19 per cent below those of California and Swedish boys of the same age. Winnipeg girls

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were 14 per cent lower. Winnipeg boys who attended private schools and thereby were exposed to more physical education than public school boys were also inferior in work capacity to Californians. In an older age group, Winnipeg nurses were much inferior to Swedish nurses. Young male adults differed less, but the results still favoured the Swedish people.

After completing a work capacity study in Philadelphia Rodahl and Issekutz (62) stated that one needs to exercise caution when comparing the physical work capacities of people in different countries since differences in physical work capacity can be demonstrated between one city and another and between different schools in the same city (61). In the Philadelphia study the differences between children in Stockholm and Philadelphia were about the same as the differences in children from north and south Philadelphia. However, the differences in Philadelphia were minimal when body weight was taken into consideration (61).

Literature Pertaining to Fitness Changes Over the Summer Holidays. In this area there has again been very little work.

In a spring-fall test-retest situation of Winnipeg boys age 10-11 Cummings and Danzinger (28) reported no changes in PWC_{170}.

In a similar study in Sweden, Adams, et al (1) found a non-significant change over the summer holidays. The authors felt the difference was not significant because the sample was small (n = 47), but it is interesting to note that most

of the boys and girls who increased their working capacities over the holidays, had initial values below the average for their age group, i.e., they tended to increase toward the normal.

CHAPTER III

METHODS AND PROCEDURE

In order to construct a random sample which would be representative of the secondary school population of the province of Alberta, Mr. Hastinov (40) of the Edmonton branch of the Dominion Bureau of Statistics was consulted. Mr. Hastinov supplied the names of 45 cities, towns and villages located in the province which were normally used in the Bureau's labour force studies. These communities were considered to be geographically, socially and economically representative of the province of Alberta. A visit was then paid to the Alberta Department of Education in order to obtain an approximation of the number of grade 10-12 students in each of the aforementioned communities. Enrollment records from June 1963 for public and separate secondary schools were obtained and the number of students in each school was ascertained by counting the names on the individual class records. It was discovered there were approximately 29,741 students in the designated schools (45). It was decided that 3 per cent of this sample or about 900 students could be tested in the time available for this study. This compared very favourably with the 1 per cent sample normally used by the Bureau of Statistics.

Permission to carry out the study was then sought from, and granted by, Dr. T.C. Byrne, Chief Superintendent of Schools for the province of Alberta. Dr. Byrne also supplied the names and addresses of the principals and super-

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intendents whose schools would be involved in the study.

These principals and superintendents were contacted by letter and permission was asked for the investigators to enter their schools. In all cases the response was favourable. Class lists were obtained from the individual schools either by visiting the school involved or having the principal of the school send his class lists to the experimenters. Each student was assigned a number and then 3 per cent of the school's students were chosen randomly using the random sampling technique described by Garrett (38). A table of random numbers was utilized in this procedure (33). A number of alternate subjects was also chosen in order to overcome the problem of absentees, abnormal subjects and students who had quit school since the class lists were published. The sample, then, was slightly unrandom due to this technique.

When the experimenters visited his/her school the student to be tested was presented with a letter asking him/her to appear at a designated place in the school at an appointed time. Each subject was then tested by the Astrand-Ryhming predicted maximal oxygen intake test.

The testing programme started on April 14, 1964 and was completed on June 5, 1964 and is designated as Experiment II.

A total of 1024 male and female subjects was tested during this phase of the experiment. Usable predicted maximal oxygen intake data, however, was recorded for only

917 subjects (500 males and 417 females).

During July and August 1964, 29 male (22 of whom had taken part in Experiment II) and 27 female (20 of whom had taken part in Experiment II) subjects of secondary school age were tested at the Research Laboratory of the Faculty of Physical Education, University of Alberta, Edmonton. These subjects were tested by both the Astrand actual maximal oxygen intake test and the Astrand-Ryhming predicted test so that these values could be compared. Predicted values were also recorded for each subject during the first work load of the maximal test. This testing programme is designated as Experiment I.

The experiments were conducted by three investigators who were trained in all aspects of the testing procedure.

<u>The Astrand-Ryhming Predicted Maximal Oxygen Intake Test.</u>

The following equipment was required:-

1) a Monark bicycle ergometer similar to the one described by Von Dobeln (62): 2) an electrical metronome; 3) a stop-watch for measuring "work-time"; 4) a stop-watch with precision of 1/10 of a second; 5) a Borg scale, model 4124C; 6) a tape measure.

A truck was used to transport the bicycle ergometer from school to school.

The testing procedure closely followed the description given by Astrand (14). The bicycle ergometer was carefully adjusted before each test so that the pendulum weight was set at "0" in order that the work load could be precisely set.

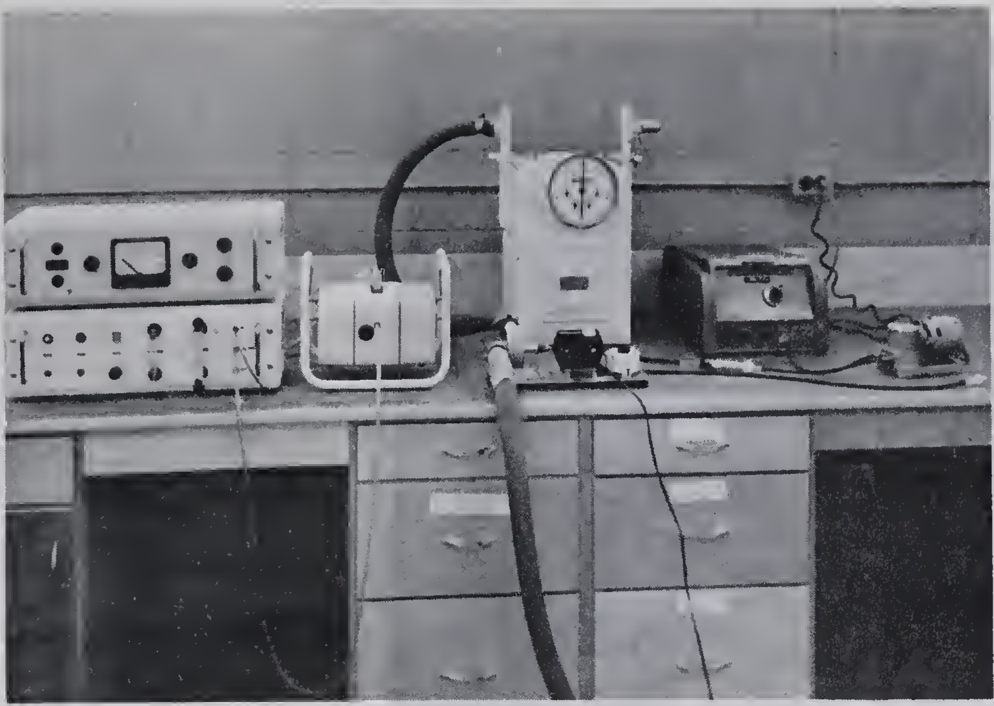

FIGURE III – i Godart CO_2 Analyzer, Volume Meter, Beckman E–z O_2 Analyzer

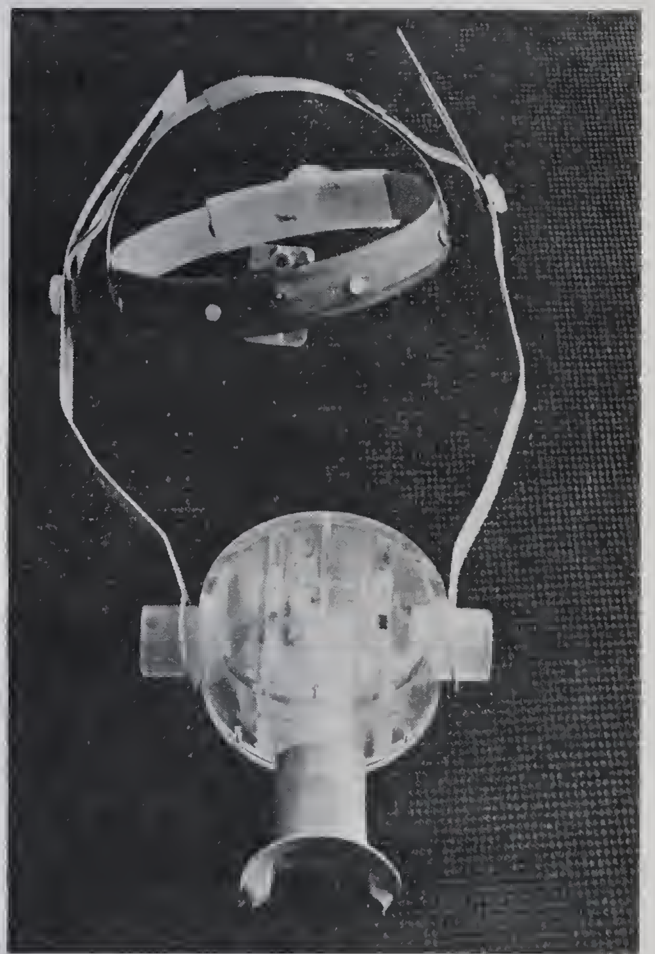

FIGURE III – ii Modified Otis McKerrow Valve with light weight head gear.

FIGURE III – iii Monark GCI Bicycle Ergometer

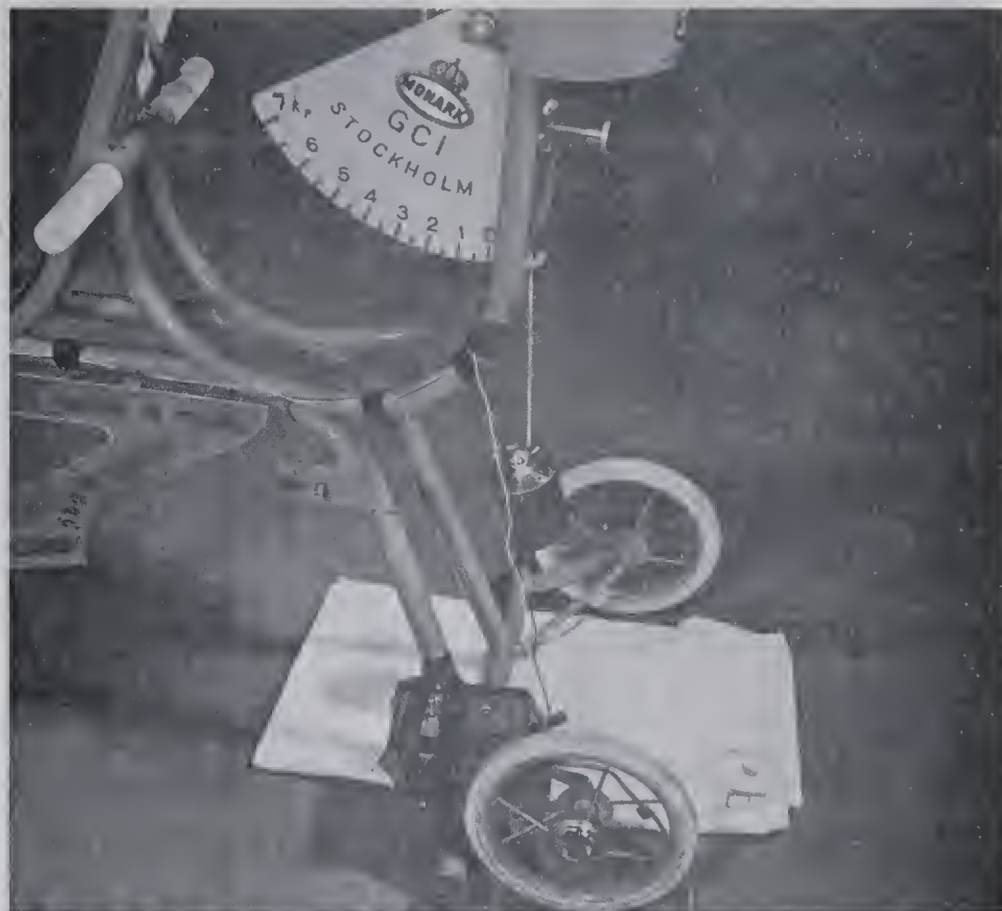

FIGURE III – iv Calibration of Monark Bicycle using 2 kilogram weight.

FIGURE III – v Astrand–Ryhming predicted maximal oxygen intake test. Note: palpation heart rate technique, placement of electrodes for female subject, metronome, electrocardiograph.

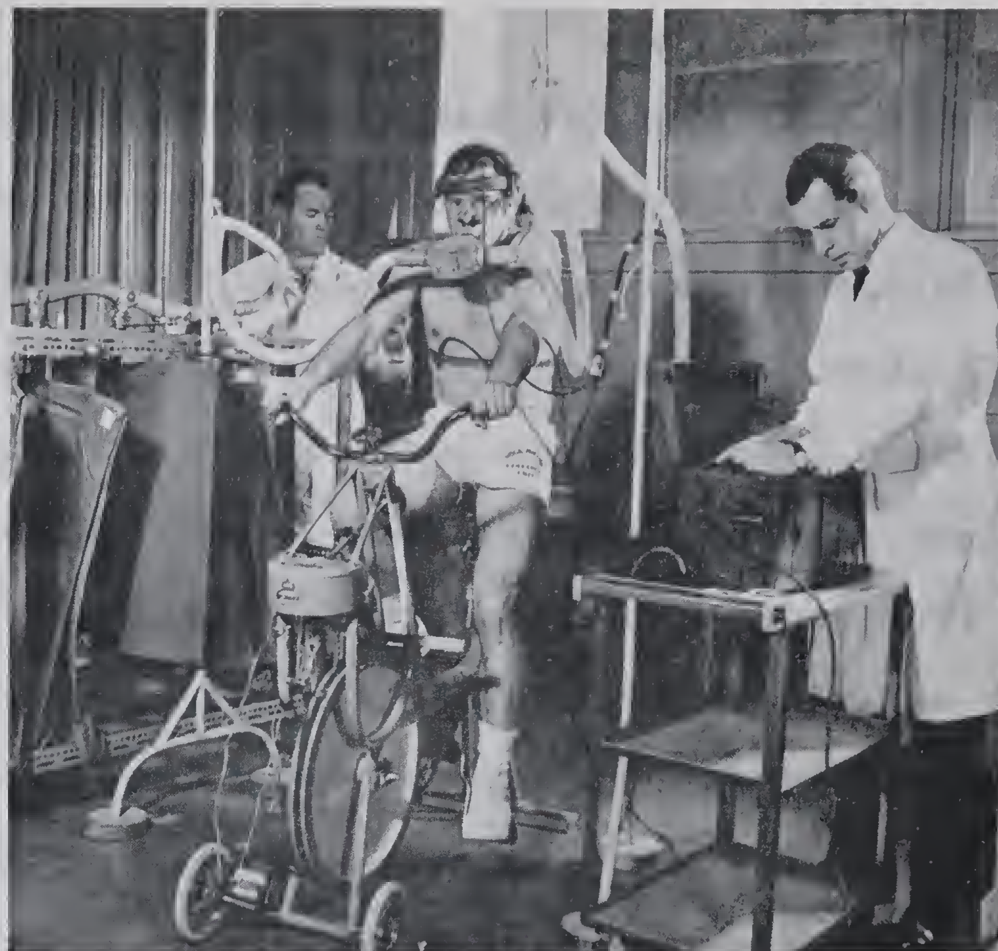

FIGURE III – vi Astrand actual maximal oxygen intake test. Note placement of electrodes for male subject.

FIGURE III – vii Palpation heart rate technique during Astrand actual test.

Testing conditions varied slightly from school to school since it was necessary to use whatever facilities made available at the individual school. Medical rooms, equipment rooms and spare classrooms were used. This made it impossible to control environmental conditions.

The subject to be tested appeared at the testing station at his appointed time. He/she performed the test in gym clothes or street clothes depending upon his/her preference. If the subject had no gym clothes but wished to change, sweat suits were available for the subject's use. Before the test, the age, height, and weight of each subject was recorded in months, inches and pounds respectively. He/she was questioned about his/her smoking habits, whether or not he/she rode a bicycle, his/her general athletic activities. He/she was also given a brief description of what the test required and the purpose of the test and the study.

The subject then mounted the bicycle ergometer and the seat was adjusted to the individual's comfort (Figure III-v). Normally the subject sat so that the front part of the sole of his/her foot was placed on the pedal and the front part of the knee was straight above the tip of the foot. A pre-exercise heart rate was then recorded. The metronome was set at 100 beats per minute so that the subject would pedal at 50 revolutions per minute and the subject was allowed to pedal against no work load until he/she could pedal at the correct cadence. The work load was then set

and the "work-time" watch was started. The work load was set subjectively but normally the boys started at a work load of 600 kpm/min. while the girls began at 300 kpm/min. Heart rates were taken during the last 15-20 seconds of each minute of exercise by the palpation method at the corotid artery. The time taken for 30 pulse beats was recorded to the nearest 1/10 of a second and converted to beats per minute using Astrand's tables (14).

After 4-5 minutes the pulse rate generally reached a steady state and the mean pulse rate between the fifth and sixth minute was designated as the working pulse. If a steady state was not found at this time, the exercise was continued until a constant level was reached. If the pulse rate reached the steady state between 125 and 170 beats per minute after 6 minutes the test was terminated. If the initial work load was not heavy enough to raise the pulse rate of the individual over 125 beats per minute the work load was increased until a steady state was attained. An attempt was made to have the individual reach the steady state at approximately 150 beats per minute since the predicted value is considered to be more accurate at higher pulse rates.

The individuals' maximal oxygen intake was then determined from the steady state heart rate and the work load by employing a table (Appendix C) prepared from the Astrand-Ryhming nomogram. All predicted values were then multiplied by the correction factor of 1.1 described by Astrand (14).

Due to the nature of tb testing schedule it was impossible to control factors such as smoking, eating and exercising before the test even though these factors may have some bearing on the results (14,63).

Astrand Actual Maximal Oxygen Intake Test. Actual maximal intake values (Figure III-vi) were measured following the procedure of Astrand (7,9,11) which were slightly modified by Glassford (39). The test was modified such that the subjects, (if they were able) worked one additional level after the apparent maximal oxygen intake had been reached. All subjects performing this test were pronounced healthy by a physician.

The test procedure is similar to that described for the predicted test in that the subject worked at a set work load on the Monark bicycle ergometer and pedalled in time with the metronome. For this part of the experiment each subject was dressed in gym clothes and expired gas was collected. Each subject's age and weight was recorded at both testing sessions. Height was recorded at the first test only. Pre-exercise pulse rates were also recorded.

The test proceeded as follows: the male subjects pedalled at a work load of 600 kpm (the females at 300 kpm) for 6 minutes. At 3 minutes and 30 seconds of the ride, the subject was connected to an Otis McKerrow two-way breathing valve by means of a rubber mouth piece and his nose was completely closed with a nasal clamp (Figure III -ii). Expired gas was collected in Douglas bags between the fifth

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and sixth minutes and the oxygen consumption for that minute was calculated. The 6 minute ride was followed by a five minute rest, the work load was increased and the subject again pedalled for 6 minutes. This procedure was repeated at ever-increasing work loads until the maximal oxygen intake was reached. As the work loads increased the riding times decreased due to fatigue. Thus the higher work loads were less than 6 minutes' duration and it was found that some subjects could pedal for no longer than one minute at the highest work load, even when highly motivated.

Due to the fact that most subjects were unable to complete the full work time at high work loads, it was necessary at times to collect the expired gas for only seconds and in a few cases, as little as 15 seconds.

The maximal oxygen intake was considered to have been reached when the difference between two successive recordings on separate work levels was less than 80 ml. of oxygen per minute which was considered to be a significant difference (6). The subject then was requested to attempt the next work load if he was able.

Methods of Determing Oxygen Consumption.

Predicted Test. The maximal oxygen consumption was predicted from the modified nomogram by Astrand and Ryhming (6) which utilizes the steady state heart rate and the work load which produces that particular steady state. In Experiment I heart rates were recorded both by the palpation

method and the electrocardiograph.

Actual Test. The expired air in the Douglas bag was analyzed for the precentage of carbon dioxide using a KK Godart Capnograph infra-red carbon dioxide analyzer, #802 American Meter Company Gasometer and then corrected for temperature and pressure (see Figure III-i).

The oxygen consumption was calculated by the following method (cited in 39).

1. Corrected volume of expired air is:

   Ve air STPD = Ve ATPS x the factor for reducing a volume of moist gas to a volume of dry gas at S.T.P.

2. The correction per cent of oxygen in the expired air is: $FeO_2 = \text{Analyzer reading} \times \frac{2.5}{1000}$

3. The volume of inspired air is:

   $$\text{Vi air STPD} = \text{Ve air STPD} \times \frac{FeN_2}{F_1N_2} \quad \text{where}$$

   $F_1N_2 = 79.03$

4. The total volume of oxygen inspired is:

   $Vi\ O_2 = \text{Vi air} \times \frac{Fi\ O_2}{100}$ where $F_1O_2 = 20.94$

5. The volume of expired oxygen is:

   $$Ve\ O_2 = \frac{Fe\ O_2}{100} \times \text{Ve air}$$

6. The amount of oxygen consumed is:

   $VO_2 = ViO_2 - Ve\ O_2$

   where:

(a) Fe = % of a particular gas in expired air

(b) Fi = % of a particular gas in inspired air

(c) Ve = volume expired

(d) Vi = volume inspired

(e) ATPS = Atmospheric temperature, pressure, saturated.

(f) STPD = Standard temperature, pressure, saturated

(g) STP = Standard pressure, temperature

Recording of Heart Rates. Heart rates during Experiment I were recorded using the 30 beat palpation technique described by Astrand (14) (Figure III-v) and on a Sanborn portable electrocardiograph (Figure III-v) from which an attempt was made to obtain a 24 to 30 beat complex. For the male subjects the leads from the electrocardiogram were attached to two chest electrotrodes and to a reference electrode placed on the subjects' forehead (Figure III-vi). For the female subjects, two arm electrodes and a reference electrode to the head were employed (Figure III-v).

The heart rate values recorded in Experiment I were from the electrocardiograph wherever possible. If the electrocardiograph values were not available then the palpation heart rates (corrected) were used. The recorded heart rates in Experiment II were obtained by the palpation technique (corrected). The procedure for correction of palpation heart rates is described in Appendix D.

Testing Schedule. In Experiment I testing schedules were arranged such that approximately one-half the subjects

completed the predicted (submaximal) test first and the maximal test second, and the other half in the reverse order. The schedule was arranged so that the subject appeared for his/her second test not less than two days but not more than seven days after the initial test.

Calibration of Instruments. The KK Godart Capnograph infra-red carbon dioxide analyzer and Beckman #E-2 oxygen analyzer were calibrated before each test using the required calibration gases. The composition of the calibration gases was evaluated using the Scholander procedure. The rate of flow through the #802 American Meter Company Gasometer had been previously calibrated and found to be in error. Suitable corrections were used to correct for this discrepancy. The procedures used for the corrections are described in Appendix D.

The sinus balance of the bicycle ergometer was calibrated using the technique described by Astrand (14). For this calibration a set of stainless steel weights, #750 Class S-1, Serial No. 7 Y 1458, Seeder Kohlbusch, Seko, Englewood, N.J., U.S.A. used by the Faculty of Engineering, University of Alberta, was used (Figure III-iv).

A more complete description of the calibration techniques employed can be found in reference 39.

Statistical Analysis. In Experiment I, the Astrand actual maximal oxygen intake test and the Astrand-Ryhming predicted maximal oxygen test were analyzed, under three experimental conditions, for both male and female subjects,

to determine if significant differences between the means existed. The null hypothesis states that there is no difference between the means. The paired sample technique was employed to eliminate extraneous factors. Using this method, one need not assume the two variances to be equal or that the values of the two means are independent (33:125). This method is described by Dixon and Massey (33:126).

The above technique was also employed to evaluate whether or not changes in mean maximal oxygen consumption had taken place over the summer vacation.

In both Experiments I and II differences in the means of the maximal oxygen intake for the two sexes were also analyzed for both the actual and predicted tests. This problem, of course, required the use of independent samples. The method used is outlined by Dixon and Massey (33:122). If the variances of the two groups were significantly different, as determined by an F test for independent samples, then a slightly different procedure was employed (33:123).

Coefficients of correlation between the predicted and actual maximal oxygen intake test values under the varying test conditions were computed following Ferguson's (36:92) procedure. The test of significance for the correlation coefficients is described by Kenney and Keeping (50:266).

The regression lines describing the relationship between the actual and predicted maximal oxygen consumption values were determined following the method described by Dixon and Massey (33:191).

CHAPTER IV

RESULTS AND DISCUSSION

Results

Means for Height and Weight: Table I gives the mean height and weight for the male and female subjects who took part in Experiments I and II.

TABLE I

MEAN PHYSICAL CHARACTERISTICS OF EXPERIMENTAL SUBJECTS

	Sex	Height		Weight(kg)	
Experiment I		in.	cm.	Actual Test	Pred.Test
	M	68.47	173.91	64.04	64.03
	F	64.31	163.35	59.00	58.89
Experiment II					
	M	68.96	175.16		65.61
	F	64.15	162.94		55.34

Means, Variances, Standard Deviations and Standard Errors of the Means for the Maximal Oxygen Intake Tests: The means, standard deviations, and variances for maximal oxygen consumption obtained on the actual and predicted tests from Experiment I are given in Table II.

The values shown below were calculated from the total data available from each of the tests. It should be noted that complete results are not available for each subject since

TABLE II

MEAN MAXIMAL OXYGEN CONSUMPTION VALUES

			MAXIMAL OXYGEN CONSUMPTION			
Test	Sex	N	Mean	S.D.	Variance	Standard Error of the Mean
1/min.						
Astrand	M	26	3.07	± 0.419	0.175	±0.08
Actual	F	24	1.96	± 0.252	0.064	±0.05
Astrand Ryhming	M	28	2.86	± 0.523	0.273	±0.10
Predicted	F	26	1.84	± 0.313	0.098	±0.07
ml/kg/min						
Astrand	M	26	48.17	± 5.942	35.050	±1.17
Actual	F	24	33.56	± 4.908	24.087	±1.00
Astrand Ryhming	M	28	44.88	± 8.273	68.437	±1.56
Predicted	F	26	31.25	± 4.234	17.924	±0.83

it was not always possible to obtain a steady state heart rate during the submaximal test or to attain a maximal value for oxygen consumption. The differences between the actual and predicted tests and the sex differences are discussed in more detail below, but it should be noted that in all cases the Astrand-Ryhming test has a mean maximal oxygen intake lower than that obtained from the Astrand actual test and the males have attained considerably larger mean maximal oxygen intakes than the females.

Actual vs. Predicted Maximal Oxygen Intake: Means, Variances, Standard Deviations, Standard Errors of the Means, Per Cent Errors. As stated above, during Experiment I it was not possible to obtain complete information on all 29 male or 27 female subjects due to experimental variables.

Therefore, information on the predicted maximal oxygen consumption was compared to that of the actual maximal oxygen consumption under three conditions. The sexes were treated separately due to the fact the means of the oxygen consumption values were somewhat larger for males than for females.

The three conditions were:

(I) the results from the actual (maximal) test were compared to the results from the predicted (submaximal) test when the predicted values were taken from the submaximal test which was held on a separate day from the actual test,

(II) the results from the actual test were compared to the results from the predicted test when the predicted values were taken from the first work level of the maximal test,

(III) the results from the actual test were compared to the results from the predicted test when the predicted values were taken from the second predicted test regardless of whether the predicted value came from the submaximal test or the first work level of the maximal test.

In this subsection of the problem only paired samples have been utilized.

From Table III it can be seen that for both male and female subjects, the Astrand-Ryhming predicted test underestimated the actual test. For the male subjects this difference was statistically significant at the .01 level of confidence under all three testing conditions. However, for the female subjects the mean difference between the pre-

TABLE III

ACTUAL VS PREDICTED MAXIMAL OXYGEN INTAKE VALUES

Test Conditions Male Subjects	N	Mean	S.D.	Variance	Standard Error of the Mean	Per Cent Difference
		Maximal Oxygen Consumption (l/min.)				
I Astrand Actual	25	3.08**	±0.425	0.180	±0.08	9.74
Astrand-Ryhming Predicted	25	2.78	±0.457	0.209	±0.09	
II Astrand Actual	22	3.16**	±0.332	0.110	±0.07	10.13
Astrand-Ryhming Predicted	22	2.84	±0.425	0.180	±0.09	
III Astrand Actual	24	3.08**	±0.460	0.212	±0.09	10.39
Astrand-Ryhming Predicted	24	2.76	±0.571	0.327	±0.12	
Female Subjects						
I Astrand Actual	23	1.98	±0.271	0.074	±0.06	5.56
Astrand-Ryhming Predicted	23	1.87	±0.319	0.102	±0.07	
II Astrand Actual	22	1.93	±0.286	0.066	±0.05	4.15
Astrand-Ryhming Predicted	22	1.85	±0.286	0.082	±0.07	
III Astrand Actual	23	1.98*	±0.271	0.074	±0.06	6.57
Astrand-Ryhming Predicted	23	1.85	±0.276	0.076	±0.06	

* Means statistically significant at the .05 level of confidence
** Means statistically significant at the .01 level of confidence
\+ Variances statistically significant at the .10 level of confidence
++ Variances statistically significant at the .02 level of confidence

dicted and actual values was not statistically significant under conditions I and II but the difference was statistically significant for condition III at the .05 level of confidence.

Where the mean differences are expressed as percentage of the mean actual maximal oxygen intake (per cent difference $= \frac{\text{actual value} - \text{predicted value}}{\text{actual value}} \times 100\%$) the predicted test underestimated the actual test by (I) 9.74, (II) 10.13, and (III) 10.39 per cent for the male subjects and (I) 5.56, (II) 4.15, and (III) 6.57 per cent for the female subjects under the three experimental conditions.

For both sexes, the variance of the predicted test maximal oxygen consumption values was not significantly different from the variance of the actual test at the two per cent level of confidence.

Correlation Coefficients Between Actual and Predicted Values. The correlation coefficients between the values obtained from the Astrand actual maximal oxygen intake and those obtained from the Astrand-Ryhming predicted maximal oxygen intake test were calculated for the three testing conditions mentioned previously. The correlations found for both male and female subjects and expressed in both l/min and ml/kg/min are found in Table IV.

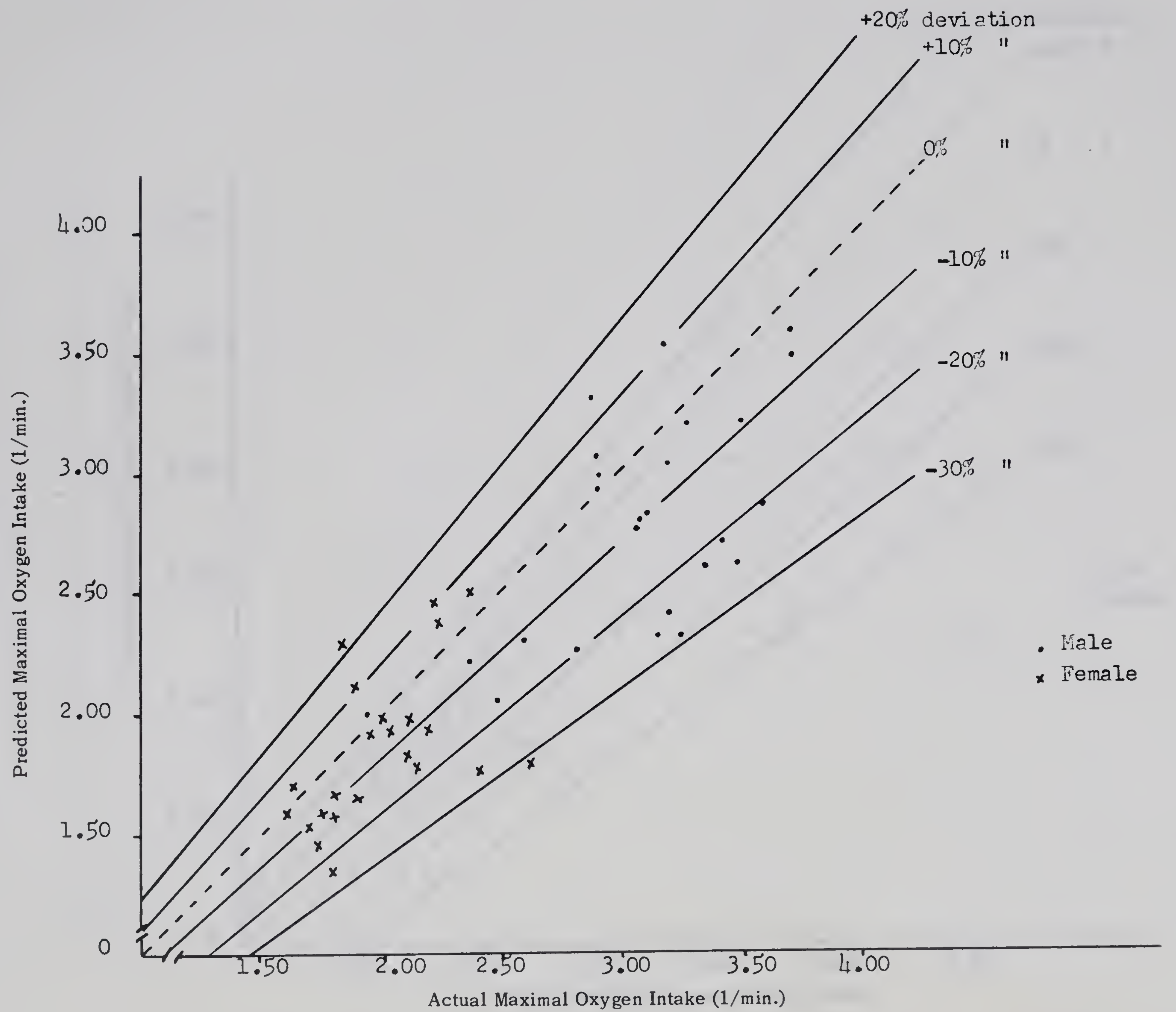
When maximal oxygen intake is expressed in l/min, all correlations, except those obtained for females under condition (III) (i.e., the maximal values were correlated with the submaximal values obtained from the second test the subject

performed), were found to be significantly different from zero. The correlations for males under conditions (I) and (III) and females under condition (I) were statistically significantly from zero at the one per cent level of confidence while the correlations for males under condition (III) and females under condition II were significant at the five per cent level of confidence.

The correlations for maximal oxygen consumption with body weight divided out are quite different. The correlations for females under conditions (I) and (III) are not significantly different from zero. Those for males under conditions (I) and (III) are significant at the .01 level of confidence while for condition (II), for both males and females, the correlations are significantly different from zero at the .05 level of confidence.

It is interesting to note that the effect of dividing out body weight was to raise some correlations and to lower others. For male subjects the changes in the correlations were not significant for all three test conditions (p=.05). The same is true for female subjects for condition (II). The data from conditions (I) and III) for the female subjects was not analyzed since at least one of the correlations under these conditions was not significantly different from zero. The accompanying graphs showing the data of the various conditions which resulted in these correlation coefficients (when maximal oxygen intake is expressed in l/min) can be seen in

FIGURE IV – i ACTUAL vs PREDICTED MAXIMAL OXYGEN CONSUMPTION (CONDITION I)



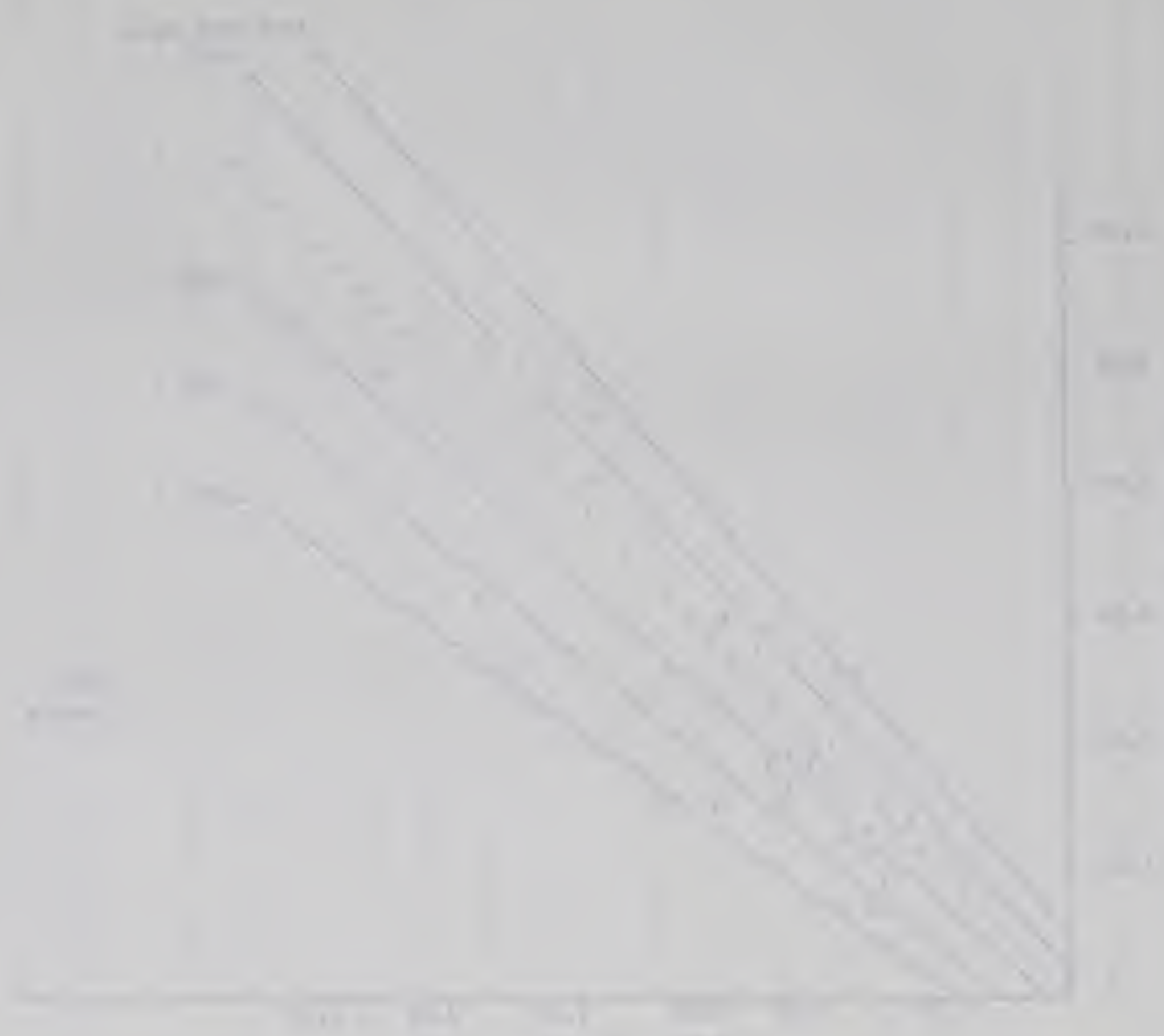
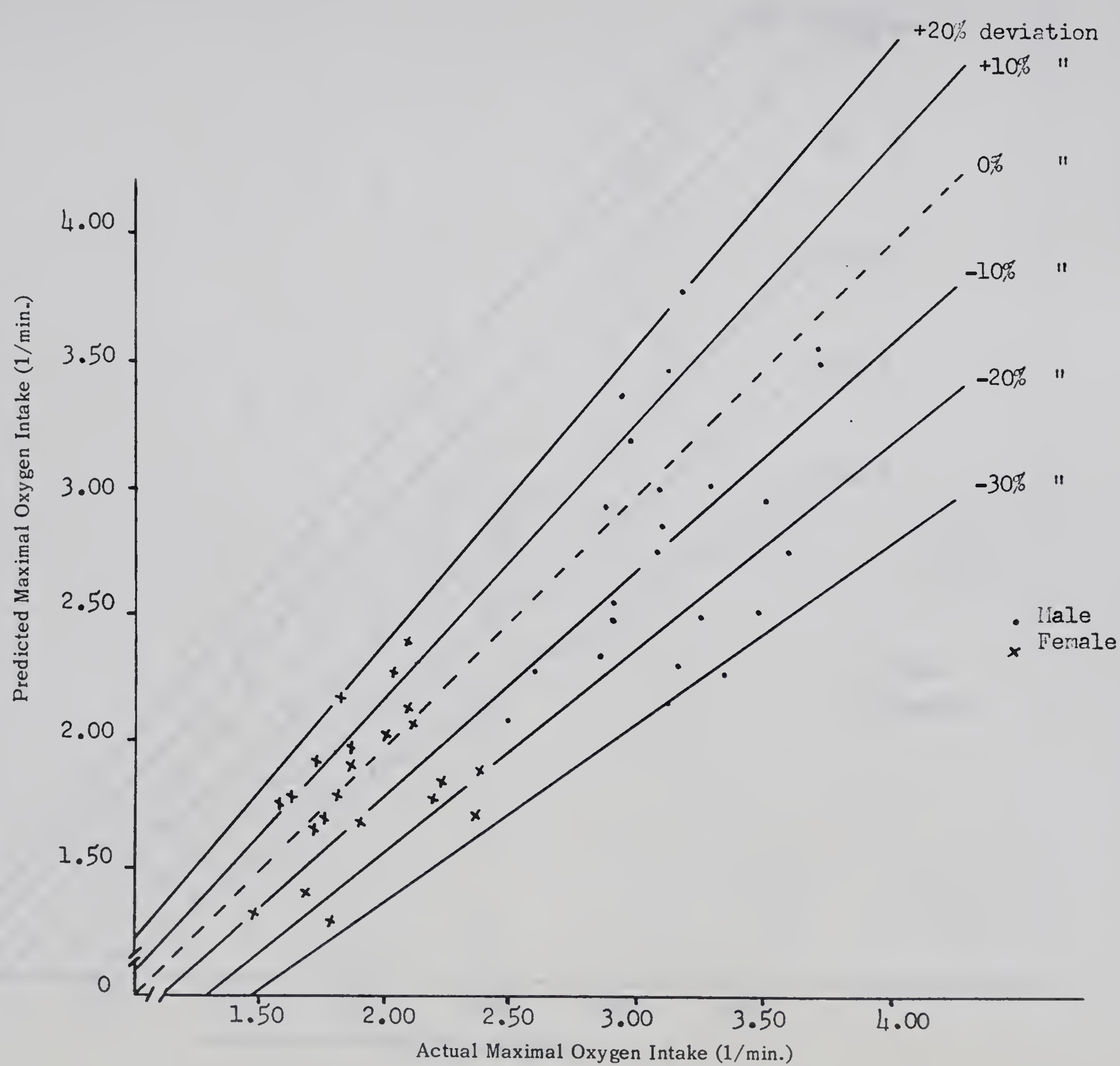


FIGURE IV – ii ACTUAL vs PREDICTED MAXIMAL OXYGEN CONSUMPTION (CONDITION II)



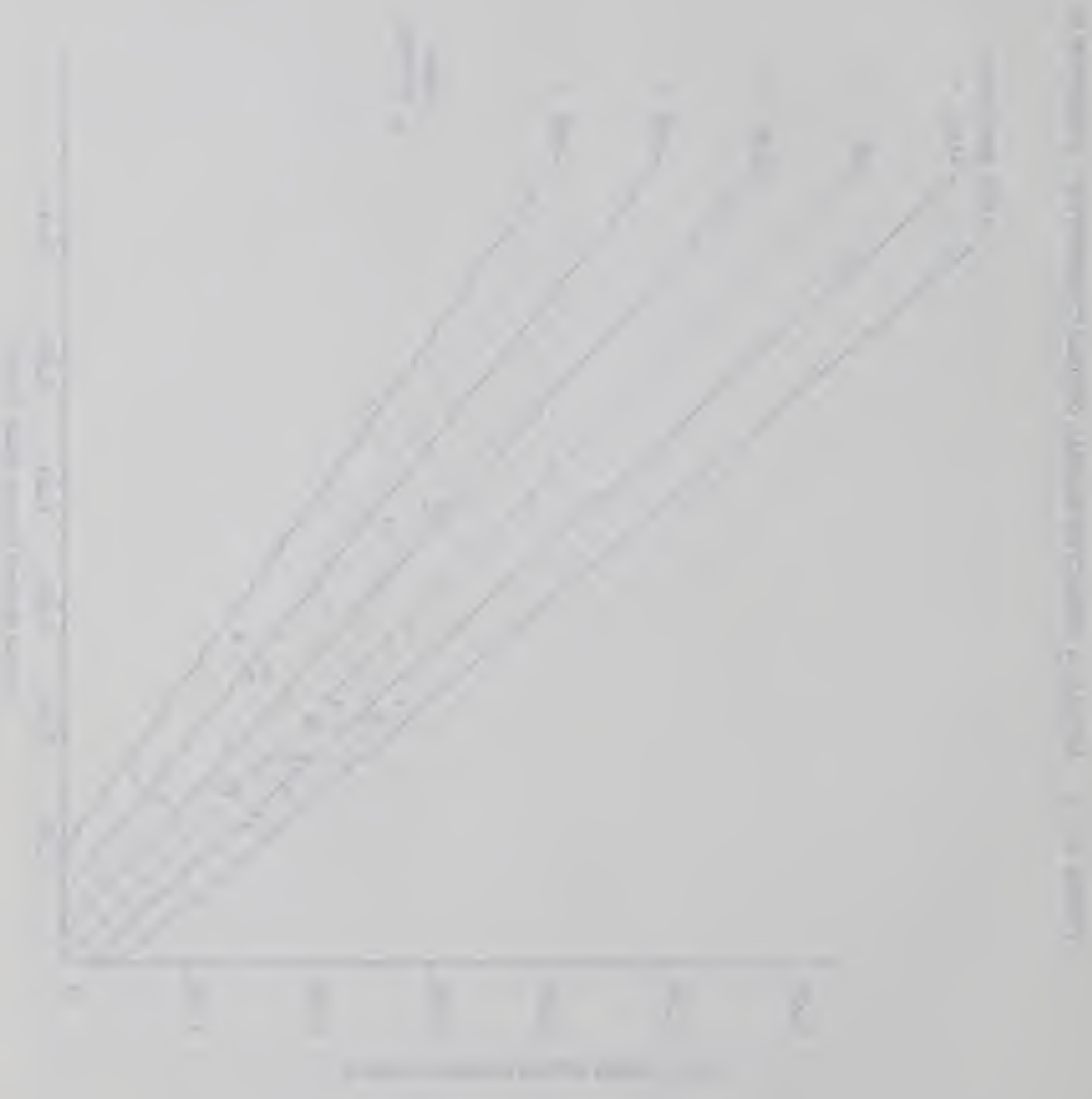
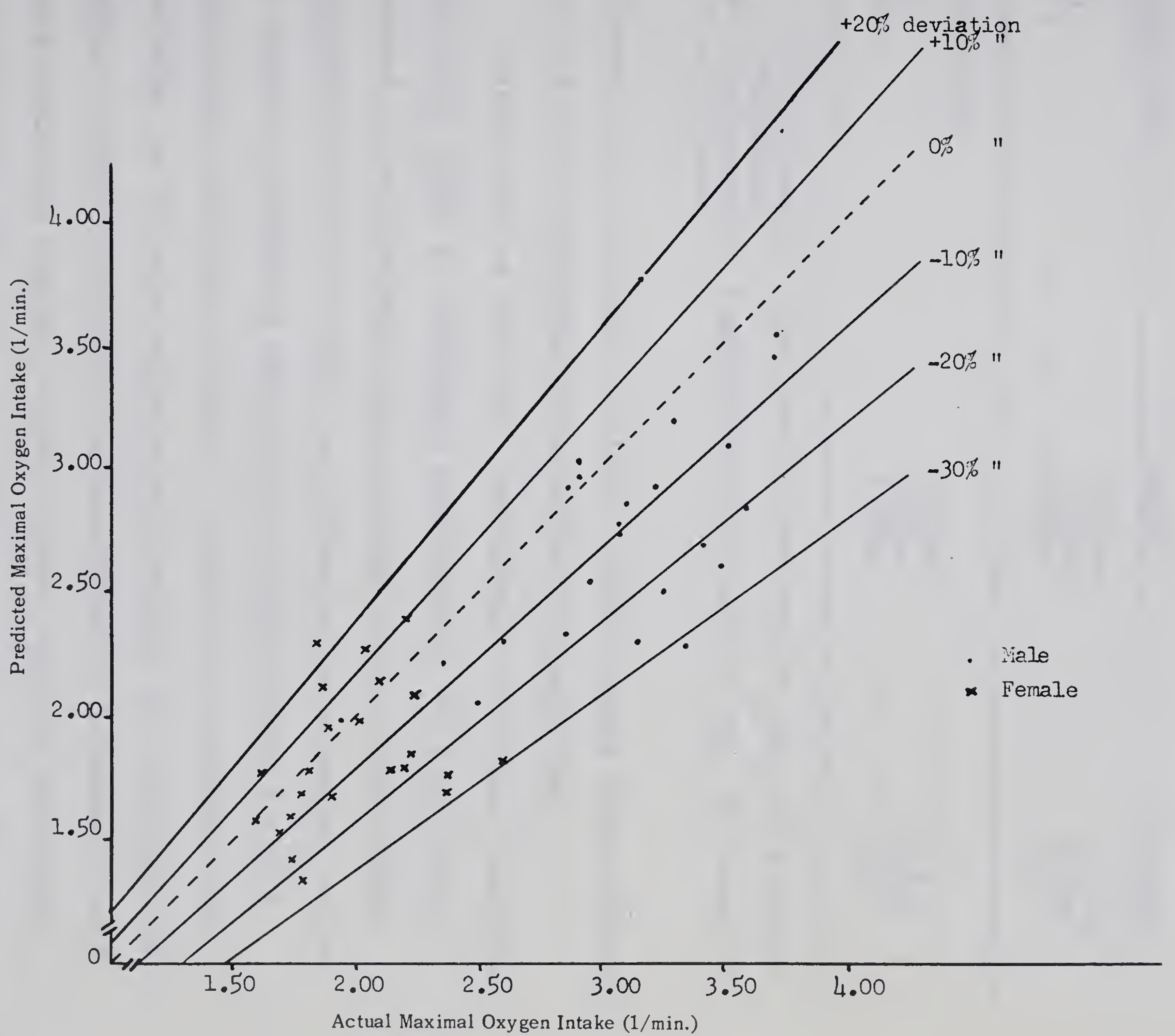


FIGURE IV – iii ACTUAL vs PREDICTED MAXIMAL OXYGEN CONSUMPTION (CONDITION III)



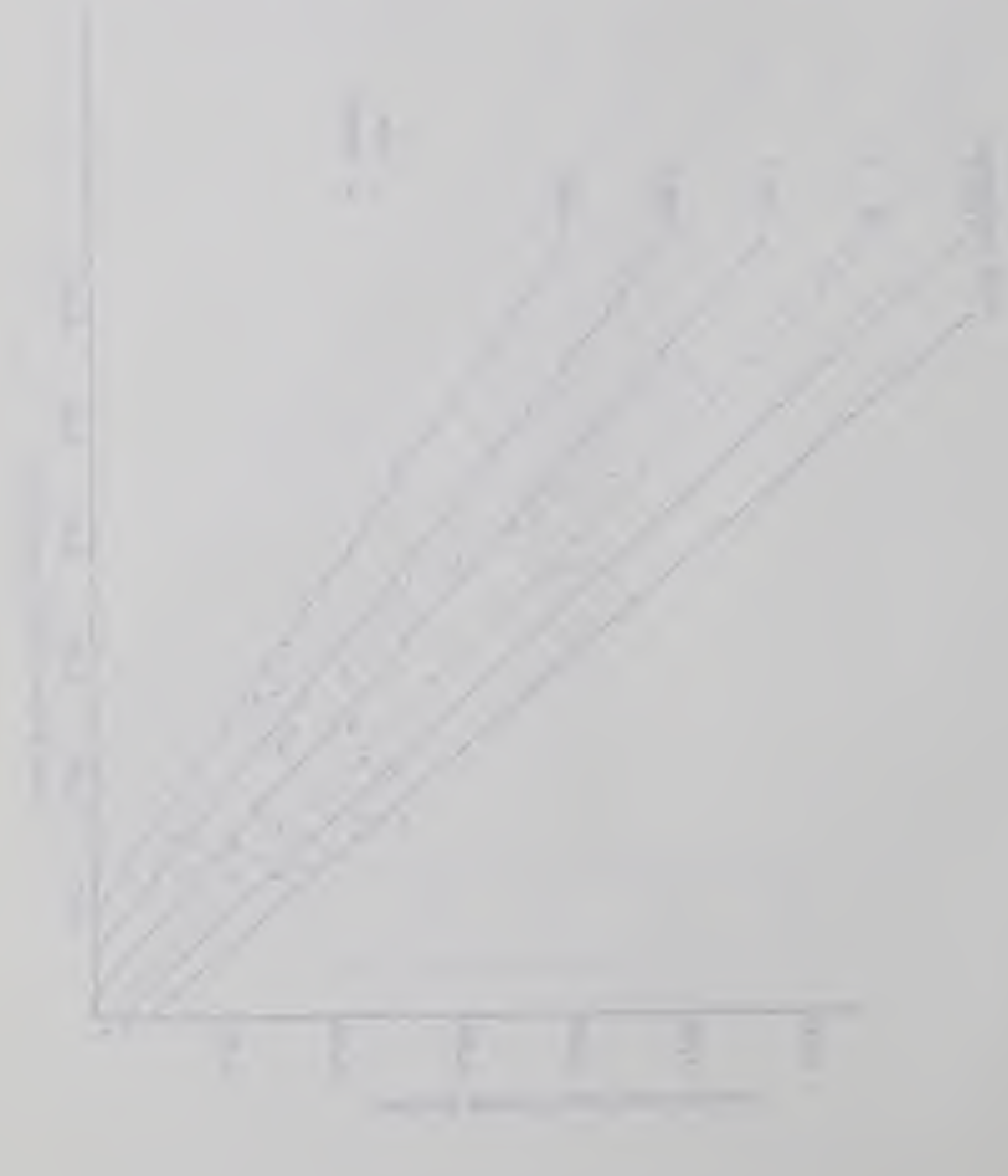


TABLE IV

CORRELATION COEFFICIENTS BETWEEN ACTUAL AND PREDICTED MAXIMAL OXYGEN INTAKE VALUES

Astrand-Ryhming Predicted Test	Astrand Actual Test	
Condition	Males	Females
l/min		
I	0.62**	0.53**
II	0.57**	0.50*
III	0.51*	0.31
ml/kg/min		
I	0.65**	0.33
II	0.43*	0.51*
III	0.56**	0.27

* Statistically significant from zero at the .05 level of confidence.
** Statistically significant from zero at the .01 level of confidence.

Figures (IV-i) through (IV-iii). These graphs also indicate the per cent deviations from perfect correlation.

Since none of the three submaximal conditions described above was found to correlate particularly well with the Astrand actual maximal oxygen intake test, it was deemed necessary to test whether the criteria for a maximal value of oxygen consumption used by the investigators in this experiment could be at fault. In order to determine this, the data for 18 male subjects who reached the criterion for maximal oxygen consumption as described by Astrand (6) and whose predicted maximal oxygen intake could be determined from the nomogram as it was presented by Ryhming, was analyzed

under these experimental conditions the correlation coefficient 0.55 which was to be significantly different from zero at the .01 level of confidence.

Regression Lines for Predicted and Actual Maximal Oxygen Intake Values. Regression lines were constructed for each sex for the three testing conditions in Experiment I. The regression lines again express the distribution of the predicted and actual values, and are in the form of y on x, i.e., the sum of squares of the distances parallel to the y axis from the plotted points to the line are minimized. The standard error of the estimate has also been recorded, i.e., the deviations of the sample points from the estimated regression line. This data is presented in Table V.

TABLE V

REGRESSION LINES FOR ACTUAL AND PREDICTED MAXIMAL OXYGEN INTAKE VALUES

Test Condition	Regression Line	Standard Error of Estimate.
Males		
I	Y = 0.515 x +1.65	±0.142
II	Y = 0.492 x +1.89	±0.264
III	Y = 0.408 x +1.95	±0.390
Females		
I	Y = 0.450 x +1.14	±0.226
II	Y = 0.448 x +1.10	±0.220
III	Y = 0.307 x +1.41	±0.261

Maximal Oxygen Intake Values for Male and Female Subjects: In order to assess the differences in work capacity between the sexes, the data from Experiments I and II have been treated separately. The data from Experiment I has further been subdivided into the predicted and actual tests. The values have been expressed in both litres per minute and ml/kg/min. The material from Experiment II has further been subdivided chronologically into age groups. The data from Experiment I was not treated for age due to the relatively small size of the sample. In Table VI, for purpose of comparing the means and variances between male and female subjects in Experiment II, the age groups 14 and 15 and the groups 19, 20, 21 have been combined due to the small number of subjects in these younger and older groups.

The results indicate that for all the experimental conditions studied the mean values found for the maximal oxygen consumption of the male subjects were superior to that of the female subjects. This is true when the oxygen consumption is expressed in l/min or in ml/kg/min. This relationship holds for both the actual and the predicted tests. In all cases, except for the over 19 age group with body weight divided out, the difference in mean values of the male and female subjects is statistically significant at the .01 level of confidence. For this latter group the means are significantly different at the .05 level.

In Experiment I the per cent differences between the sexes for the actual test are 36.16 per cent and 30.32 per cent resp-

TABLE VI

COMPARISON OF MAXIMAL OXYGEN CONSUMPTION VALUES BETWEEN MALE AND FEMALE SUBJECTS

EXPERIMENT I

Age	Sex	N	Means	S.D.	Variance	Standard Error of the Mean	Per Cent Difference Between Means
Actual Values - 1/min	M	26	3.07**	±0.418	0.175++	±0.08	36.16
	F	24	1.96	±0.252	0.064	±0.05	
ml/kg/min	M	26	48.17**	±5.942	35.305	±1.17	30.32
	F	24	33.56	±4.908	24.087	±1.00	
Predicted Values 1/min	M	28	2.86**	±0.523	0.273++	±0.10	35.66
	F	26	1.84	±0.313	0.098	±0.07	
ml/kg/min.	M	28	44.88**	±8.273	68.437++	±1.56	30.37
	F	26	31.25	±4.234	17.924	±0.83	

continued ....

TABLE VI continued ....

EXPERIMENT II
1/min

Age	Sex		N		Mean	S.D.		Variance	Standard Error of the mean	Per Cent Difference Between Means
14	M		6		2.33	±0.429		0.184	±0.18	
	F		4		1.89	±0.580		0.336	±0.29	
		M68		2.77**			0.300+			29.24
		F83		1.96			0.194			
15	M		62		2.81	±0.536		0.287	±0.07	
	F		79		11.97	±0.436		0.191	±0.05	
16	M		146		2.94**	±0.565		0.319++	±0.05	30.95
	F		152		2.03	±0.366		0.134	±0.03	
17	M		162		2.99**	±0.619		0.383++	±0.05	29.77
	F		131		2.10	±0.403		0.162	±0.04	
18	M		83		3.03**	±0.681		0.464+	±0.08	31.02
	F		39		2.09	±0.502		0.252	±0.08	
19	M		36		2.19	±0.541		0.293	±0.09	
	F		9		2.15	±0.665		0.443	±0.22	
				2.92**			0.286			
20	M	M41	4		2.99	±0.601	0.347	0.361		27.74
	F	F12	2	2.11	2.13	±0.883		0.695		
21	M		1		3.19					
	F		1		1.67					

continued ....

TABLE VI
EXPERIMENT II continued .....

ml/kg/min

Age	Sex		N	Mean		S.D.	Variance		Standard Error of the Mean	Per Cent Difference Between Means
14	M		6		41.26	±7.020		49.301	±2.87	
	F		4		34.91	±7.861		61.783	±3.93	
		M68		46.53**			74.100			21.84
		F83		36.37			52.712			
15	M		62		47.04	±8.623		74.350	±1.10	
	F		79		36.44	±7.275		52.925	±0.82	
16	M		146		46.12**	±8.911		79.169+	±0.74	19.77
	F		152		37.00	±7.105		50.479	±0.58	
17	M		161		45.68**	±9.384		88.071+	±0.74	15.98
	F		131		38.38	±7.247		52.516	±0.63	
18	M		83		44.93**	±8.265		68.309	±0.91	18.58
	F		39		36.58	±7.671		58.842	±1.23	
19	M		36		43.33	±7.744		59.974	±1.29	
	F		9		39.29	±12.687		160.959	±4.23	
20	M	M41	4	43.54*	45.62		64.812	157.941		
	F	F12	2	38.55	36.08		118.780	0.183		11.46
21	M		1		42.63					
	F		1		36.72					

* Difference between means statistically significant at the .05 level of confidence.
** Difference between means statistically significant at the .01 level of confidence.
\+ Difference between variances statistically significant at the .10 level of confidence.
\++ Difference between variances statistically significant at the .02 level of confidence.
Note: Data not included in table is due to the small sample size for that age group.

ectively when the maximal oxygen consumption is expressed in l/min and in ml/kg/min. The predicted tests show corresponding differences of 35.66 and 30.37 per cent and thus are of the same order as those of the actual tests (Table VI).

In Experiment II the per cent differences between the predicted values of the male and female subjects expressed in l/min are of approximately the same order for all age groups, varying from 27.74 per cent to 31.02 per cent. They are, however, approximately 5 to 8 per cent less than the per cent difference for the predicted test in Experiment I. When the per cent difference in Experiment II is expressed in terms of ml/kg/min there are wider deviations. For the age groups 14 to 18 the differences vary from 15.93 to 21.84 per cent while the per cent difference for the 19 and over age group is only 11.45 per cent. These values also deviate considerably from the per cent difference obtained from the predicted test with body weight divided out in Experiment I.

The F tests between the variances of the maximal oxygen consumption for males and females show diverse results. The variances between the sexes for the actual tests in Experiment I are significantly different at the .01 level of confidence when oxygen consumption is expressed in l/min, but, when it is expressed in ml/kg/min the difference is not statistically significant. However, the predicted values in Experiment I show significant differences at the .01 level of confidence regardless of whether the body weight is considered or not.

In Experiment II the variances are significantly different for all age groups when oxygen consumption is expressed in l/min. The difference is significant at the .01 level of confidence for the age groups 16 and 17 but at the .05 level of confidence for the other ages. When body weight is divided out the variances are significantly different for only the 16 and 17 year old groups. This difference is statistically significant at the .01 level of confidence.

It is interesting to note that for the predicted test the male subjects show a larger variance for the age groups 16, 17, and 18 while the 19 and over and the 15 and under age groups show a larger variance for the female subjects.

Comparison of Maximal Oxygen Intake Values of Alberta School Students with Those of Other Countries. Rödahl and Issekutz (62) presented a table showing the various values of maximal oxygen intake reported by a number of investigators who had determined it on subjects of approximately the same age as those studied in the present experiment. The table is reproduced in part here (Table VII). It is noted that all age groups investigated in the present experiment were not represented in the original table, and thus, only the data on the pertinent age groups as reported by Rödahl and Issekutz is presented here. The data on the Alberta Subjects come from the actual values of Experiment I and the predicted values of Experiment II.

No statistical inferences have been drawn since markedly

different techniques were used to assess maximal oxygen consumption in the various studies. Astrand employed a treadmill test to find actual values while the Alberta study employed a bicycle ergometer and a predictive test as well as an actual test.

Conclusions are difficult to draw, not only owing to the differing testing techniques but also due to the varying number of subjects used in each experiment. However, in all cases, the Astrand values are considerably greater than the values reported by other investigators. In most cases the Alberta sample records higher values than the samples of the remaining investigators, even when the predicted values are employed (it is stated above that the values obtained on the predicted test usually underestimated the actual value). Comparisons to be made with the actual values from Alberta are also hampered due to the paucity of subjects in the 14 and 18 year old age groups.

Changes in Maximal Oxygen Consumption Over the Summer Vacation. The predicted maximal oxygen consumption values from Experiment II were compared with the predicted maximal oxygen consumption values from Experiment I for 16 male subjects and 17 female subjects who took part in both phases of the investigation. The maximal oxygen consumptions' were expressed in both l/min and ml/kg/min in order to account for any changes in body weight during the interim period.

TABLE VII

MAXIMAL OXYGEN INTAKE VALUES REPORTED FROM VARIOUS COUNTRIES AND CITIES

		1952 Stockholm (Astrand)		1938 Boston (Robinson)		1959 Freiburg Germany (Reindell et al)		1959 Philadelphia (Rodahl et al)		1964 Alberta EXP. I.		1964 Alberta EXP. II.	
Age	Sex	N	1/min	N	1/min	N	1/min	N	1/min	N	1 /min	N	1/min
14	M	5	3.16	9	2.60	42	1.69	16	1.85	-	-	6	2.33
	F	5	2.52	-	-	-	-	19	1.34	2	1.84	4	1.89
16	M	3	3.35	-	-	49	2.18	10	2.03	10	2.95	146	2.94
	F	8	2.66	-	-	-	-	9	1.26	7	2.00	152	2.03
18	M	3	3.87	11	3.60	51	2.67	10	2.07	1	3.11	83	3.03
	F	-	-	-	-	-	-	5	1.22	1	2.36	39	2.09

TABLE VIII

CHANGES IN MAXIMAL OXYGEN INTAKE DURING THE SUMMER VACATION

	Mean Difference	
	Males	Females
l/min	-0.14	-0.22*
ml/kg/min	-2.996	-4.717**

*Mean difference significant at the .05 level of confidence
**Mean difference significant at the .01 level of confidence

The results given in Table VIII, show that the male subjects showed a slight decrease in the mean maximal oxygen consumption but this decrease was not statistically significant. Of the 16 male subjects only 5 increased their maximal oxygen consumptions between the tests when oxygen intake is recorded in l/min and only 3 when it is expressed in ml/kg/min.

The female subjects showed a significant decrease at the .05 level of confidence when the maximal oxygen consumption is reported in l/min and at the .01 level of confidence when it expressed in ml/kg/min. Only 4 of 17 girls increased their maximal oxygen consumptions during the vacation period when the oxygen consumption is recorded in l/min (one showed no change) or in ml/kg/min.

The difference between the decreases in work capacity for the male and female subjects was 0.08 litres per minute. When these values were expressed in ml/kg/min., this difference became 1.721. In both cases, the females demonstrated a greater decrease in their maximal oxygen consumption values over the summer vacation than did the males.

Discussion

Validity of the Predicted Test. Since many exercise physiologists (12,42,58,61,70) consider the aerobic capacity (maximal oxygen consumption) to be the best measure of fitness (work capacity) importance has been placed on a simple, rapid method of assessing it. The purpose of this study was to investigate the validity of the Astrand-Ryhming nomogram for the prediction of aerobic capacity and its application to males and females of secondary school age.

Little work has been recorded on the aerobic capacity of adolescents but from Table VII it can be seen that for the ages, for which comparable data is available, the values obtained here fall within the limits obtained by other investigators. This must be looked upon with caution since the techniques for assessing the maximal oxygen consumption have varied from study to study and there has been considerable time lapse between the studies.

Table II shows the mean values of maximal oxygen consumption obtained with the Astrand actual and the Astrand - Ryhming

predicted tests. The 26 males tested on the Astrand actual test had a mean value of 3.17 ± 0.419 (mean±standard deviation) litres per min., while the 28 male subjects on the Astrand predicted test had a mean value of 2.86 ± 0.523 litres per minute. The 24 females participating in the Astrand actual test obtained a mean value of 2.60 ± 0.475 litres per minute while the 26 who were assessed on the predicted test reached a mean value of 1.84 ± 0.313 litres per minute. The corresponding values expressed as ml/kg/min were 48.17 ± 5.942, 33.56 ± 4.908, 44.88 ± 8.273 and 31.25 ± 4.234 ml/kg/min respectively.

For the purposes of investigating the differences between the Astrand actual and the Astrand predicted tests the results of the predicted tests were evaluated under three conditions. The study of the various conditions, it was thought, would lead to the development of optimal testing conditions in future studies. A description of these conditions accompanies Table III. From Table III it can be seen that for the male subjects under all three conditions the means of the actual and predicted tests are significantly different at the .01 level of confidence. For the female subjects, however, the mean predicted values under conditions I and II are not significantly different from the actual values. Under condition III the means of the two tests are significantly different at the .05 level of confidence. These results differ somewhat from those reported by Astrand

[illegible]

and Ryhming (15) when they first introduced the nomogram. In that instance the predicted values for men were closer to the actual values than those predicted for the females.

The reason for this discrepancy could be, (i) the nomogram does predict the maximal oxygen consumption more accurately for females than for males, or (ii) the females were not able to attain their true maximal value. The merits of this second possibility are discussed more completely under the heading of sex differences. It should be noted that the actual mean value of maximal oxygen consumption is superior to the predicted mean value for both sexes under all three testing conditions. Similarly, Morse, et al (57) found that for adolescent boys the nomogram underpredicted the actual maximal oxygen consumption by an average 0.2 (7.9) per cent. This difference was not statistically significant. Rowell, et al (63) discovered that maximal oxygen intake predicted from the nomogram was 26.8 ± 7.2 per cent less than the observed value for seven sedentary young males before training. Conversely, Baycroft (18) and Glassford (39) found the mean predicted values to be significantly greater than the mean actual values. Hettinger, et al (42) obtained analagous results.

In all probability these differences are due to the variations in the subjects employed in the various investigations. The subjects of Baycroft and Glassford were young male adults 17 to 35 years of age, who were trained to some

degree. They would be somewhat similar to the subjects from whose maximal oxygen consumption values the original nomogram was constructed. The subjects used in the present experiment were younger than those employed in Astrand's original study (11), and in various degrees of training. The subjects used by Rowell, <u>et al</u> (63) were sedentary males and it is noted that the magnitude of underestimation decreased by approximately one-half as a result of a 3 month period of training.

The underestimation is greatly decreased when one employs the correction factor for 15 year olds recently introduced by Astrand (14).

The underestimation of the maximal oxygen intake when expressed as a percentage is approximately 10 per cent for male subjects and 5.5 per cent for female subjects when the correction factor recently introduced by Astrand (14) is used. This deviation is considerably less than that reported by Rowell, et al (63) for his sedentary subjects before training (26.8 $\pm$ 7.2 per cent) and it is still somewhat less than the observed underestimation of their subjects after a 2½ - 3 month training period (13.7 per cent). The underestimation for the females in the present investigation is of the same magnitude as those for the endurance athletes of Rowell, <u>et al</u> (5.6 per cent). The underestimation for males in the present study is of a larger dimension. Astrand and Ryhming (15) reported standard deviations of 14.4 per cent for female subjects and 10.4 per cent for males when the subjects worked

at low work levels and only 6.7 per cent and 9.4 per cent for males and females respectively when they worked at a higher rate of work. One should be reminded, however, that the studies discussed above employed various types of subjects and various testing techniques.

In the present experiment the variances between the predicted and actual tests were found not to be significantly different at the .02 level of confidence for both male and female subjects. Glassford (39) reported a significantly greater variance for the Astrand-Ryhming predicted test than for three actual maximal oxygen consumption tests, two of which were conducted on a treadmill, and the third being the Astrand actual test. Further investigation should be conducted to determine if differences in variances exist in other samples and, if so, to what extent the test is affected.

The correlation coefficients under each of the three testing conditons previously mentioned showed variability between the sexes and among the conditions. From Table IV it can be seen that the correlation coefficients for the male subjects are 0.62, 0.57 and 0.51 and those for the female subjects are 0.53, 0.50 and 0.31 when maximal oxygen consumption was expressed in l/min. Only the correlation coefficient for females under condition III was not significantly different from zero.

The correlation coefficient of r = 0.62 for male subjects under condition I agrees favourable with Glassford's (39) figure of 0.65 and Baycroft's (18) of 0.62. However, de Vries

and Klafs (30) reported a correlation of 0.736 between predicted values from the Astrand-Ryhming nomogram and actual maximal oxygen consumption determinations.

When body weight was divided out diverse results were observed. Some of the correlations increased, other decreased. For the male subjects the correlations of 0.65, 0.43 and 0.56 are in the range of those reported by other investigators, viz., Glassford (0.63), Baycroft (0.47) and de Vries and Klafs (0.522). Analagous variations were also observed for the female subjects but there is no data available with which comparisons can be made.

The fact that the predicted test has been proven to be more valid for females than for males in the present investigation and yet the male values show higher correlation coefficients could perhaps be explained in the following way: it is possible the Astrand-Ryhming test can predict quite accurately for females but it cannot differentiate between very close values, since the male values are of a larger magnitude there is more chance of larger deviations between these subjects than for the closer female values.

The accompanying graphs (Figures IV-i, IV-ii, IV-iii) indicate there are wide deviations betwen individual predicted and actual maximal oxygen intake values. It is evident that in the majority of the cases there is a negative deviation, i.e., the predicted value is less than the actual value. The negative deviations are of a greater magnitude than the positive deviations, as much as 20 to 30 per cent, while only

a few positive deviations are greater than 10 per cent. These deviations are much greater than those of 10.4 per cent and 14.4 per cent for men and women, respectively, reported by Astrand and Ryhming (15) when their subjects performed at low work levels.

Thus, one may conclude in view of these findings that the most valid results obtained in this experiment were attained under the conditions in which the maximal and submaximal tests were conducted at two different sessions separated by not less than two, or more than seven days. If more work is conducted in this area one should be able to ascertain the most optimal conditions for the testing programme.

Many variables exist which appear to affect the predictive value of the submaximal test. Rowell, et al (63) have mentioned the fact that at any level of submaximal work, the pulse rate can vary independently of the oxygen uptake but directly with the emotional state or degree of excitement of the subject (70). It also varies with the degree of physical conditioning, elapsed time after the previous meal, total circulating hemoglobin, degree of hydration of the subject, alterations in ambient temperature and hydrostatically induced changes resulting from prolonged erect posture.

The factor of emotion must be considered of utmost importance. One need only look at the pre-exercise pulse rates of the subjects in Experiment I (see Appendix C) in

order to perceive this emotional effect. This factor can easily be understood since the subjects of Experiment I were exposed to a strange situation, a research laboratory which they had never seen before, and in the case of the maximal test, a circumstance in which they would be encouraged to work to near exhaustion. In Experiment II the test was conducted in more familiar surroundings but the test itself was an emotional factor. Rowell, et al (63) stress the emotional effect of the experimental procedure and the subsequent rise in heart rate and therefore the lowering of predicted maximal oxygen intake.

The emotional effect, could in all likelihood be reduced if the experimental subject was made familiar with the laboratory surroundings. This may involve pre-test sessions, the number of which may vary between individuals. If the emotional factor can be reduced it is possible the predicted test values would estimate those of the actual test very closely, as long as one used the correction factor for age which was recently introduced by Astrand (14).

The factor of strength must also be considered. Most subjects complained of fatigue in the quadriceps muscles during the maximal test rather than the upper body stress which usually accompanies the determination of maximal oxygen intake from treadmill tests. This became a limiting factor in the determination of the actual maximal oxygen intake at high work loads, since, with fatigue the subjects found it

difficult to follow the cadence of the metronome. Also, care had to be taken in choosing the increment of the work load since many of the weaker subjects could not work very long at high work loads. This is an important consideration when working with female subjects.

Rowell, et al (63) mention the effect of training. The nomogram was originally constructed from the data of well-trained subjects. They found there was great decrease in the underestimation of maximal oxygen intake when 7 sedentary subjects trained for 3 months (an improvement from 26.8 7.2 per cent to 13 per cent)(63). Even with this improvement the underestimation was still significantly greater than the 5.6 per cent underestimation observed in ten endurance athletes. The subjects in the Alberta experiment were all healthy but their degree of training varied considerably; while some were very active,conversely, others lived sedentary lives. Thus, on the basis of the findings of Rowell, et al (63) one would expect the Alberta group to show considerable variability.

The factor of work load also entered into the study since many subjects had difficulty following the cadence of the metronome. If an individual pedalled faster than the metronome rate he worked at a higher level than he would receive credit for and his maximal oxygen consumption value would be underestimated. Conversely, his maximal oxygen consumption would be overestimated if he pedalled too slowly. This variable is difficult to control, even if the experimenter

makes the subject constantly aware of it.

A further limitation on this study was that at high heart rates for low work levels the nomogram as constructed could not be used. An extrapolated nomogram was used to estimate aerobic capacities less than 1.6 l/min (uncorrected). If heart rate levels such as were obtained from the subjects who took part in this study are indicative of those of the whole population these high heart rates must be taken into consideration. At the same time a number of subjects "overshot" the critical level of 170 beats per minute even at relatively low work levels. This latter data, of course, had to be discarded.

One of the more important variables is that of the sample studied in this experiment. The age group ranged from 14 to 21 years and one must consider the changes at the age of puberty to be of some importance, especially for the younger subjects. Many subjects would have reached puberty, others had probably not yet attained it. These gross changes in the body at puberty could be expected to have some bearing on the results. What they may be, is beyond the scope of this investigation but further study into this variable should be considered.

One must concede that before Astrand-Ryhming nomogram can be widely used as a valid predictor of maximal oxygen consumption (aerobic capacity) for the age groups studied here, there is a need for more investigation into the variables which affect the predictive test. There are indications that

repeated determinations of submaximal pulse ratio may have to be employed before a heart rate, that is minimally affected by emotion and other variables, can be obtained. Rowell and his co-workers (63) state this to be particularly true for athletes.

The predicted test does differentiate between the sexes (Table VI) thus showing that it does distinguish between high and low values of maximal oxygen consumption. This indicates that it may, also, then, differentiate between well-trained and less active individuals even though it may not be able to distinguish between the aerobic capacities of individuals who are in approximately the same state of training.

Sex Differences. While the difference in work capacity between the sexes has been the topic of a few studies, little work has been reported on the differences in aerobic capacity. Astrand's (11) study is the most notable in this area.

Table VI shows that for both the actual and predicted tests in Experiment I the male values for maximal oxygen intake are significantly superior to those of the females at the .01 level of significance. This relationship exists whether the oxygen consumption is expressed in l/min. or in ml/kg/min. In Experiment II the same relationship holds for all age groups at the .01 level of confidence except in the case of the over 19 age group when body weight was divided out. Under this condition the difference is significant at

the .05 level. The basic reason for the differing results is a matter for conjecture. Astrand (12) indicated that this difference between the sexes continues to exist in the older age groups. There may be two explanations for this observation; either (i) there may be a narrowing of the difference due to the fact that the males are no longer increasing their aerobic capacity with age, while the females are continuing to increase; or (ii) the smaller difference may be due to sampling procedure since only a small number of females (as compared to males) in this age group were investigated. This difference in work capacity (not specifically aerobic capacity) has also been noted in various other studies.

From figures V-i, V-ii, and V-iii, it can readily be seen that in only a few cases do the higher female maximal oxygen consumption values overlap with the lower male values.

For the actual test a difference of 36.16 per cent was observed between the male and female maximal oxygen consumption values expressed in l/min. This difference was reduced to 30.32 per cent when body weight was considered. For the predicted test (Experiment I) the corresponding values were 35.66 per cent and 30.37 per cent respectively. The differences between the sexes in Experiment II (predicted values) varied from 27.74 to 31.02 per cent for the various age groups when maximal oxygen consumption was expressed in litres per minute. With body weight considered there was a greater range of per cent difference, from 11.46 to 21.84 per cent. Astrand (12)

reported that for adults the maximal oxygen intake during a treadmill test averaged 29 per cent lower for females than for males when oxygen consumption is expressed in litres per minute. For subjects somewhat older than 12 years the oxygen intake per kilogram body weight was about 17 per cent lower than that of males (12). The figures from Experiment II, with body weight considered, compared to this last figure stated by Astrand but both the actual and predicted figure from Experiment I show a considerable deviation.

The magnitude of the differences found in the Alberta subjects and Astrand's material may be the consequence of the Alberta testing programme being conducted on the bicycle ergometer while Astrand used a treadmill test. In 1952, Astrand (11) found that for males the oxygen intake is the same in running and cycling experiments whereas the females attained somewhat lower values during cycling as compared with running ($p = 0.05$). Therefore, there would be greater diversity between the sexes on the bicycle ergometer than on the treadmill.

According to Astrand there is little difference between the sexes in the work and rest values for different functions up to the age of puberty. After puberty it appears the male values become increasingly superior.

Astrand (11,12) explained the difference in oxygen consumption between the sexes in the following way: the average hemoglobin content of the blood is 13.7 gm/100cc in females

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

and 15.8 gm in males. The total amount of hemoglobin content for adult women is about 30 per cent less than that of males, this difference being reduced to 20 to 25 per cent in terms of body weight. For both sexes the maximal oxygen intake capacity per unit hemoglobin is the same. Thus the sex differences found in oxygen intake per kg. body weight are reflected by similar differences in total hemoglobin. He concluded that if the total quantity of hemoglobin and the maximal oxygen intake vary with the muscle mass, the female adult ought to have 15 to 20 per cent less muscular tissue per kg. body weight than the male adult. (The oxygen intake and quantity of hemoglobin per kg. of the female are 17 and 20 per cent less respectively than that of the male). This implies that the distribution of the muscles in the body is almost the same in men and women. If this difference in muscular mass in relation to weight is not accepted, the relationship between the quantity of hemoglobin (or aerobic capacity) and muscular mass must be different in man and woman. The woman's muscular mass would be excessively "great" (or small) with regard to the oxygen transport. The last alternative, according to Astrand, seems least probable.

He continues that the difference in aerobic capacity between males and females may be connected with the different amounts of adipose and active tissue between the sexes, i.e., men are better working machines than women. To eliminate the factor of adipose tissue, fat free body weight could be considered. In the 1952 study (12) the difference between aerobic

capacity per kilogram body weight and performance were of the same order during treadmill work. Females during exercise ran a distance 18.5 per cent shorter than did males (oxygen intake is 17 per cent lower).

Sjöstrand (65) observed that for males the total quantity of hemoglobin increased with age up to age 22. In the female subjects, as with the males, the quantity of hemoglobin increased up to age 12 to 13, but after this the increase was considerably less up to age 20, after which it remained constant. When body weight was considered the quantity of hemoglobin showed a manifest increase for males during the years of puberty and up to age 22, but in female subjects there was a relative decrease from age 12 to 20.

During the maximal testing program of Experiment I few of the females were able to work to high work loads. Though the majority attained maximal oxygen intake curves of the charactersitic asymptotic form there may be some doubt as to whether they attained their true maximal value since it was difficult to determine if the subject had reached her maximum or was forced to stop due to fatigue. Blood lactate concentration determinations for assessment of fatigue level were not within the scope of this experiment. Correspondingly, not all male subjects reached the criterion for attainment of maximal oxygen consumption but they could be motivated to the extent that, in the majority of the cases, it can be said subjectively that they had worked to exhaustion. As mentioned previously,

most subjects complained of local fatigue in the quadriceps muscles and this limited their performance at high work loads. Due to differences in strength between the sexes this would, in all probability, have a more pronounced effect on the female subjects. (In women, the flexors and extensors of the lower leg can develop to about 70 per cent of the strength of men (12)). A work load that is easy for a man to perform (50 per cent of his capacity) consequently means a great physical stress for a women (12).

Astrand (12) has also noted that for female subjects the limiting work factors can be more psychological than physiological (12). He believes the degree of exhaustion can be evaluated more objectively by determining the level of blood lactic acid, if the work engages large muscle groups and the period of work is not prolonged. He cites the examples of two studies, one in which the exhaustion level was objectively controlled and another in which it was not controlled. In the controlled study the difference in aerobic capacity per kilogram body weight between male and female subjects was 17 per cent while in the other it was 29 per cent. These results, he claimed, <u>may</u> depend upon the circumstance that women, as a rule, have a stronger distaste for straining themselves physically. This may account for the large difference between the male and female actual values of maximal oxygen intake recorded in Experiment I of the present investigation.

However, these statements are qualified somewhat if one

draws conclusions from Astrand's 1952 study (11). There, he states that the increasing difference, with age, in oxygen intake between the sexes, must be regarded as a consequence of sexual maturity. He concluded it was not a question of "laziness" since the females reached higher average maximal lactic acid concentration than the males for the ages 12 - 18.

Thus, it appears there is an intertwining of physiological, psychological, and social variables which comprise the reasons for the reduced work output of females after puberty. However, even if women have lower work capacities than men there is no reason to believe they cannot take part in normal labour if need be, especially in time of emergency (12).

Comparison of Work Capacity for Alberta Students and Foreign Values. There has been a widely accepted view that North American children are less fit than European children. This has been attributed to the fact that there is more mechanization in North America and more emphasis on fitness in Europe. There is, however, little objective evidence to support this view.

Table VII indicates that for mean maximal oxygen consumption values the Alberta sample compares favourably with those of Philadelphia, Boston, and Freiberg but are somewhat inferior to the Stockholm sample. No statistical inference has been attempted due to the diversity of the samples and the techniques employed to assess aerobic capacity. Another consideration pointed out by Rödahl, et al (61) is that the

Astrand study was completed in 1952 and that the figures provided may no longer reflect the current status in fitness with regard to maximal oxygen intake in Swedish subjects.

Rodahl and Issekutz (62) also discuss the possibility that the belief of wide-spread differences in work capacity between European and North American children may be in error since children tend to be active whatever their culture. Any differences, then would tend to be the result of more emphasis on physical training. It would be reasonable to assume, however, that these differences would be more marked in older adolescents and adults due to cultural implications.

One must be cautious in discussing differences between countries since Rödahl, et al (61) found significant differences in work capacity between subjects in north and south Philadelphia of the same magnitude as those between Philadelphia and Stockholm. Realistic comparisons between countries cannot be discussed until systemized, comprehensive studies are conducted simultaneously in various countries.

Changes in Work Capacity Over the Summer Vacation. Again, little work has been reported in this area. Through the study of the variables concerned with this topic certain implications could perhaps be drawn about the physical education programmes now being offered in our schools. If there is a large decrease in aerobic capacity during the vacation period this could perhaps be attributed to decreased activity on the part of the

subjects and would perhaps speak well for the physical education programme. Conversely, an increase in aerobic capacity would perhaps indicate increased activity.

The results obtained are difficult to interpret. The boys showed no significant difference in work capacity over the vacation period. Therefore, one may ascertain that, either, (i) they did not decrease their activity since school was dismissed, or (ii) physical education programmes produce little change in fitness. No record was made of the subjects' summer activity, or how it compared to their winter activity.

The girls, on the other hand, showed a significant decrease in fitness over the vacation period. This may indicate a decrease of activity since cessation of the school term.

It is interesting that the majority of subjects (male and female) showed a decreased maximal oxygen consumption on the second test. This may depend upon the factor of emotion discussed previously since both tests were predictive in nature and the second test was administered at the University of Alberta Research Laboratory which was an unfamiliar situation for the subject. Also, there may not have been time for changes to occur. Most subjects were tested initially in mid-April or early May and secondly in mid-July to mid-August. Therefore they were exposed to summer climatic conditions for no longer than four months but perhaps for as short as two months. There is also the intervening variable of final

subjects was [illegible] Consequently, an increase in [illegible] would perhaps [illegible]

The results [illegible]

The adults, on the other hand, showed a significant decrease in [illegible]

It is interesting that [illegible] Therefore [illegible] There is also the interesting [illegible]

examinations during the month of June when few students would have time for intensive physical activity.

However, the results obtained here closely parallel those of Cumming and Danzinger (28) who also found a lack of improvement in physical work capacity (PWC170) over the summer months. They concluded that climatic factors do not exert a major influence on the physical work capacity and in the absence of determined effort at physical training, summer activity would seem to be insufficient to improve physical work capacity in normal children.

On the other hand, Adams, et al (1) found that boys who had sub-normal work capacities before the summer holidays tended to show an increase in PWC_{170} when retested in the fall. However, their conclusions lacked statistical evidence.

CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this study was to investigate the validity of the Astrand-Ryhming nomogram for males and females of secondary school age by comparing values obtained from the Astrand-Ryhming "predicted" maximal oxygen intake test. The secondary purposes were to determine regression lines between the actual and predicted values, to investigate sex differences with respect to work capacity, to compare the work capacity of Alberta secondary school students with that of Europeans and Americans of a similar age, and to investigate work capacity changes during the summer vacation from school.

The study was composed of two separate investigations designated as Experiment I and Experiment II. In Experiment I maximal oxygen consumption was measured by both the Astrand-Ryhming predicted and the Astrand actual methods for 29 males and 27 females of secondary school age. In Experiment II the maximal oxygen consumption of 500 males and 417 females, who were considered to be representative of the secondary school population of the province of Alberta, was measured by the Astrand-Ryhming predicted maximal oxygen intake test. The latter subjects were chosen using a stratified random sample method.

In Experiment I the gas samples from the Astrand actual test were collected in Douglas bags and analyzed on a Godart Capnograph carbon dioxide analyzer and a Beckman #E-2 oxygen

analyzer.

The difference between the actual and predicted maximal oxygen consumption values in Experiment I were analyzed under three conditions for both sexes. These conditions were: the results from the actual test were compared to those from the predicted test when the predicted values were taken from the submaximal test which was: (I) held on a separate day from that of the actual test, (II) the first work level of the maximal test, and (III) the second predicted test irregardless of whether the predicted value came from the submaximal test or the first work level of the maximal test. Paired samples were used in order to make comparisons.

The mean maximal oxygen consumption of the Astrand-Ryhming predictive test underestimated the mean values for both sexes under the three testing conditions. The difference was statistically significant for the male subjects but not statistically significant for the females ($p = .01$) except for condition III ($p = .05$).

Correlation coefficients between the actual and predicted tests varied between the sexes and among the testing conditions. When oxygen consumption was expressed in l/min these coefficients were 0.62, 0.57, and 0.51 for the males and 0.53, 0.50 and 0.31 for the females under the three testing conditions. All were significantly different from zero except that for females under condition III, i.e., $r = 0.31$. When body weight was considered the correlations became 0.65, 0.43,

conditions.

The differences between the initial and conditioned [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]

[illegible]

The [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]

[illegible]

[illegible]

and 0.56 for males and 0.33, 0.51, and 0.27 for females. All male correlation coefficients were significantly different from zero while for the females those under conditions II and III were not significantly different from zero. The correlation coefficients for maximal oxygen consumption expressed in l/min and with body weight considered were not significantly different from each other for either sex.

Mean male maximal oxygen consumption values were statistically significantly superior to those of the female subjects for all ages regardless of whether body weight was considered or not. This relationship held for both the actual and predicted tests.

The mean maximal oxygen consumption values for Alberta secondary school students appear to be below those of Swedish subjects of similar ages but superior in most cases to those reported from other countries. However, there is no statistical justification for these statements since the data was not analyzed statistically.

Male subjects did not undergo statistically significant changes in aerobic capacity over the summer vacation ($p = .01$). Female subjects demonstrated a significant decrease when maximal oxygen consumption was expressed in l/min ($p = .05$) or ml/kg/min ($p = .01$).

On the basis of the statistical analysis the following conclusions appear to be justified.

1. The Astrand-Ryhming nomogram predicted mean maximal oxygen consumption values are equivalent to those obtained on the Astrand actual test for females of secondary school age. The predicted test was less accurate for males of the same age.

2. The nomogram underpredicts maximal oxygen consumption for males of this age group. The correction factor should be used for both males and females of this age group.

3. There is no difference between the variances of the predicted and actual test.

4. The Astrand-Ryhming predicted maximal oxygen intake test appears to differentiate between individuals who are in widely different states of training. It does not appear to differentiate between individuals who are in approximately the same state of training.

5. Many variables such as emotion, state of training, strength, and work level, appear to effect the Astrand-Ryhming predicted test.

6. The mean aerobic capacity of males is superior to that of females for all age groups studied here.

7. Though it is difficult to assess, Swedish children may have superior work capacities as compared to Alberta children. Alberta children appear to compare favourably with children of the same age of other areas.

8. The aerobic capacity of males does not change during the summer vacation period. Aerobic capacity appears to decrease for females at that time.

Recommendations. During the course of the experiment the need for further investigation into a number of parameters became evident:

1. There is a need for further investigation into optimal testing schedules for the predicted test.

2. To reduce the effect of emotion, training on the bicycle ergometer in the laboratory situation is essential.

3. The nomogram should be adjusted to account for high heart rates at low work levels.

4. Lactic acid blood concentration determinations should be investigated in order to ensure a maximal effort, on the part of the experimental subject, has occurred.

5. There is a need for more investigation into variables affecting adolescents.

6. If fitness levels between countries are to be compared there is a need for systemized studies to be conducted simultaneously in various countries.

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APPENDIX

APPENDIX A

STATISTICAL TREATMENT

STATISTICAL TREATMENT

<u>Study Design</u>. The study was composed of two experiments. Experiment I utilized the Astrand actual maximal oxygen intake test and the Astrand-Ryhming predicted maximal oxygen intake test. The following analyses were made:

1. A comparison between the mean maximal oxygen intake test values attained on the actual and predicted tests for both males and females under varying testing conditions.

2. A comparison between the male and female mean maximal oxygen consumptions attained for both the actual and predicted maximal oxygen intake tests.

3. A comparison between the values of predicted maximal oxygen consumption between the spring test (Experiment II) and the summer test (Experiment I).

4. Correlation coefficients were obtained between the actual and predicted maximal oxygen intake tests under the varying conditions in Experiment I.

5. Regression lines were constructed using the data for predicted and actual maximal oxygen intake values under the various conditions of Experiment I.

6. Various other parameters such as variance, standard deviation, and standard error of the mean, were also computed.

A one tailed test was employed to indicate the significance of the differences in means between the male and female maximal oxygen consumption values. In all other situations two tailed tests were utilized.

Statistical Procedure

Computation of the Mean

$$\bar{X} = \frac{\sum X}{N} \quad (33:16)$$

where: $\bar{X}$ = mean
N = no. of observations
X = value of observation

Computation of the Variance and Standard Deviation.

$$S^2 = \frac{\sum X^2 - \frac{(\sum X)^2}{N}}{N - 1} \quad (33:19)$$

where: S^2 = variance
N = no. of observations
X = value of observation
S = standard deviation

$$S = \sqrt{S^2}$$

Computation of the Standard Error of the Mean.

for large samples

$$SEm \text{ or } \sigma m = \frac{\sigma}{\sqrt{N}} \quad (38:185)$$

where: σ = standard deviation of the population

for small samples

$$SEm = \frac{S}{\sqrt{N}}$$

where: S = standard deviation of the sample.

Computation of the Correlation Coefficient.

$$r = \frac{N\sum XY - \sum X \sum Y}{\sqrt{\left[N\sum X^2 - (\sum X)^2\right]\left[N\sum Y^2 - (\sum Y)^2\right]}} \quad (36:92)$$

where r = correlation coefficient
X = observation of sample x
Y = observation of sample y

Computation of Regression Lines.

$$\bar{Y} = \bar{Y} + b\,(X - \bar{X}) \qquad (33{:}191)$$

Where:

$$b = \frac{\sum Xi \quad Yi - \dfrac{\sum Xi \sum Yi}{N}}{\sum Xi^2 - \dfrac{(\sum Xi)^2}{N}} \qquad (33{:}191)$$

where b = regression coefficient

Standard error of the mean.

$$Syx^2 = \frac{N-1}{N-2}\,(Sy^2 - b^2\, Sx^2) \qquad (33{:}191)$$

where: Syx^2 = mean square deviation
Sx^2 = variance of observed X values
Sy^2 = variance of observed Y values

Tests of Hypothesis Concerning the Means of Two Populations.

(i) Mean of one population is equal to the mean of a second population when σ^2 is unknown.

$$t = \frac{\bar{X}_i - \bar{X}_2}{S_p \sqrt{1/N_1 + 1/N_2}} \qquad \text{with } N_1 + N_2 - 2 \text{ d.f.} \qquad (33{:}122)$$

with

$$S^2_p = \frac{(N_1 - 1)\,S_1^2 + (N_2 - 1)S_2^2}{N_1 + N_2 - 2} \qquad (33{:}121)$$

where: S_p^2 = pooled variance
$\bar{X}_1$ = Mean of group (1)
$\bar{X}_2$ = Mean of group (2)
N_1 = no. of observations of group (1)
N_2 = no. of observations of group (2)
S_1^2 = variance of group (1)
S_2^2 = variance of group (2)

(ii) Two populations have the same mean (variances not equal).

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{S_1^2/N_1 + S_2^2/N_2}} \qquad (33:124)$$

with

$$f = \frac{\left(\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}\right)^2}{\frac{\left(\frac{S_1^2}{N_1}\right)^2}{N_1+1} + \frac{\left(\frac{S_2^2}{N_2}\right)^2}{N_2+1}} - 2 \text{ d.f.} \qquad (33:124)$$

(iii) Two Means are equal (Paired observations)

$$t = \frac{\bar{d} - o}{S/\sqrt{N}} \qquad (33:126)$$

where: $\bar{d}$ = mean of differences
S = standard deviation of the differences
N = no. of pairs of observations

with $N - 1$ d.f.

$$S^2_d = \frac{\sum d^2 - \frac{(\sum d)^2}{N}}{N - 1}$$

<u>Tests of Hypothesis Concerning the Variances of Two Populations.</u>

$$F = \frac{S_1^2}{S_2^2} \qquad (33:107)$$

where: F = variance ratio
S_1^2 = variance of group (1)
S_2^2 = variance of group (2)

with $N_1 - 1$ and $N_2 - 1$ d.f.

Significance of the Correlation Coefficient.

$$t = r\sqrt{\frac{N-2}{1-r^2}}$$

(50:266)

with N-2 d.f.

where r = correlation coefficient

Significance of the Difference between Two Correlation Coefficients.

$$z = \frac{z_{r1} - z_{r2}}{\sqrt{\frac{1}{N_1-3} + \frac{1}{N_2-3}}}$$

(36:154)

Tests of Hypothesis:

Actual vs Predicted Mean Maximal Oxygen Intake.

Males	Condition	Actual		Predicted	t	Sig. at
	I	3.08	-	2.78	3.86	.01
	II	3.16	-	2.84	3.55	.01
	III	3.08	-	2.76	3.89	.01
Females						
	I	1.98	-	1.87	1.94	Not sig.
	II	1.93	-	1.85	1.39	Not sig.
	III	1.98	-	1.85	2.09	.05

(Refer to Table III)

Male vs Female Mean Maximal Oxygen Intake Values.

Experiment I	Male	-	Female	t	sig. at
Actual values 1/min.	3.07	-	1.96	11.47	.01
ml/kg/min	48.17	-	33.56	9.44	.01
Predicted Values 1/min.	2.86	-	1.84	8.80	.01
ml/kg/min.	44.88	-	31.25	7.70	.01

Experiment II

(i) 1/min.

AGE	Male	-	Female	t	sig. at
15 and under	2.77	-	1.96	10.11	.01
16	2.94	-	2.03	16.36	.01
17	2.99	-	2.10	14.84	.01
18	3.03	-	2.09	7.74	.01
19 and over	2.92	-	2.11	4.53	.01

(ii) ml/kg/min.

AGE	Male	-	Female	t	sig. at
15 and under	46.53	-	36.37	7.90	.01
16	46.12	-	37.00	9.11	.01
17	45.68	-	38.38	7.21	.01
18	44.93	-	36.58	5.33	.01
19 and over	43.54	-	38.55	1.74	.05

(Refer to Table VI)

Changes in Mean Maximal Oxygen Intake During the Summer Vacation.

Males	$\bar{d}$	t	sig. at
1/min.	-0.14	1.16	not. sig.
ml/kg/min.	-2.996	1.67	not. sig.
Females			
1/min.	-0.22	2.46	.05
ml/kg/min.	-4.717	3.21	.01

APPENDIX B

INDIVIDUAL SCORE SHEETS

ASTRAND BICYCLE ERGOMETER TEST

DATE OF TEST ________________

NAME ________________________ SEX ______ DATE OF BIRTH ________

ADDRESS ____________________________ HT. _____ WT. ________

SCHOOL ______________________________ GRADE ______________

RESIDENCE - Urban (Over 5,000) ________

Rural (Under 1,000)_______(1000-5000)_____Farm ____

SMOKE: Yes _____ No _____

Do you ride a Bicycle? Yes ____ No ____ Would you be tested again? Yes ____ No _____

Gr. 12 Do you plan to attend U. of A. in Sept. 1964? Yes____No ___

Do you participate in the regular P.E. program? Yes _____ No_____

DATA

TIME minutes	TIME 30 bts.	TABLE Bts/min.	WORK. Load

Resting Pulse ______ Steady State Pulse ______ Pred. Max. O_2______

REMARKS:

Name: ____________ Date of Birth: ____________ Height: ______ in. Sex: ______

Previously tested at ____________________ High School

Submaximal VO_2 Test

Date ____________

Weight ______ lbs. ______ kgm.

Resting Pulse Rate ______ b/min.

Time (Min)	Heart Rate: Palpation: Time (sec)	Heart Rate: Palpation: H.R. b/min.	Heart Rate: ECG: b/min	Work Load (K.p.m)
1				
2				
3				
4				
5				
6				
7				
8				
Steady State				

Predicted VO_2 ______ l.

______ ml./Kgm

Maximal VO_2 Test

Date ____________

Weight ______ lbs. ______ Kgm.

Resting Pulse Rate ________ b/min.

Remarks:

Work Load Kpm	HEART RATES: PALPATION 1	2	3	4	5	6	HEART RATES: ECG 1	2	3	4	5	6	ANALYSIS: CO_2	O_2	Vol.	VO_2	DUPLICATE: CO_2	O_2	VO_2

Actual VO_2 ________ l.

________ ml./kgm

Steady State: Heart Rate ______ b./min.

Work Load ______ kp.m.

Predicted VO_2 from Maximal Test: ______ l.

______ ml./kg

NAME ______________________________

DATE ______________________________

$t =$ ______________ $^{\circ}C$

B.P.= ______________ mm. Hg

Factor= ______________

$F_EO_2 =$ __________ $\frac{x\ 2.5}{1000} =$ __________ $F_IO_2 = 20.94$

F_EO_2 (corr.) = __________ $F_ICO_2 = 00.03$

$F_ECO_2 =$ __________ $F_IN_2 = 79.03$

$F_EN_2 =$ __________

V_E ATPS= __________ l./min.

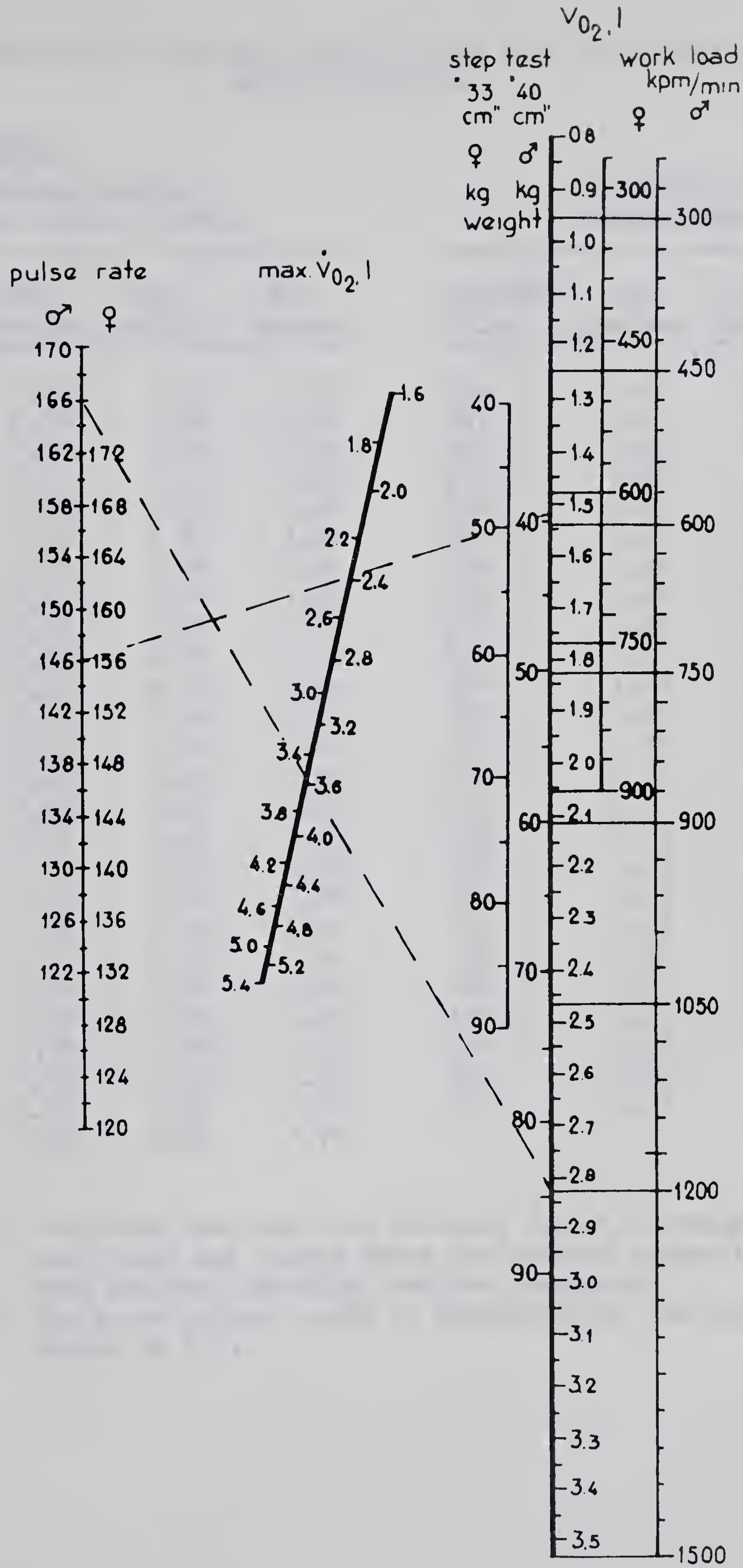
V_E STPD= __________ x __________ = __________ l./min.

V_I STPD= __________ x __________ = __________

$VO_2 =$ (__________ x .2094) - (__________ x __________) = ______ l./min.

APPENDIX C

RAW SCORES



The Åstrand nomogram for the calculation of aerobic work capacity from submaximal pulse rates and O_2-uptake values. (*From I. Åstrand, Acta Physiol. Scand., Suppl.* **49,** 169, 1960. *Reproduced by permission of the publisher.*)

PREDICTION OF MAXIMAL OXYGEN UPTAKE FROM THE ASTRAND RYHMING NOMOGRAM

Female Subjects

	Predicted Maximal Oxygen Uptake (l/min)		
Working Pulse	300 kpm/min	450 kpm/min	600 kpm/min
120	2.58	3.35	4.10
121	2.50	3.30	4.00
122	2.50	3.20	3.90
123	2.40	3.15	3.85
124	2.40	3.10	3.80
125	2.34	3.04	3.70
126	2.30	2.98	3.60
127	2.24	2.90	3.54
128	2.20	2.85	3.52
129	2.15	2.78	3.44
130	2.10	2.75	3.40
131	2.07	2.70	3.35
132	2.03	2.67	3.25
133	2.00	2.63	3.20
134	2.00	2.60	3.18
135	1.95	2.55	3.12
136	1.92	2.50	3.05
137	1.90	2.45	3.00
138	1.84	2.40	2.97
139	1.81	2.38	2.92
140	1.80	2.34	2.84
141	1.77	2.30	2.80
142	1.75	2.28	2.78
143	1.72	2.25	2.75
144	1.70	2.20	2.72
145	1.64	2.18	2.70

	Predicted Maximal Oxygen Uptake (l/min)		
Working Pulse	300 kpm/min	450 kpm/min	600 kpm/min
146	1.63	2.15	2.64
147	1.61	2.13	2.62
148	1.60	2.10	2.58
149	1.55	2.07	2.55
150	1.53	2.04	2.50
151	1.50	2.00	2.48
152	1.50	1.98	2.45
153	1.46	1.95	2.40
154	1.45	1.93	2.38
155	1.42	1.92	2.35
156	1.40	1.90	2.32
157	1.38	1.87	2.30
158	1.35	1.85	2.27
159	1.34	1.82	2.24
160	1.31	1.80	2.22
161	1.30	1.78	2.20
162	1.28	1.75	2.18
163	1.25	1.72	2.15
164	1.23	1.71	2.12
165	1.21	1.70	2.10
166	1.20	1.68	2.08
167	1.17	1.65	2.05
168	1.16	1.63	2.03
169	1.15	1.61	2.00
170	1.13	1.60	1.99

Note: (i) The above data was read directly from the nomogram. For work loads not listed above the maximal oxygen intake values were recorded directly from the nomogram.

(ii) The above values should be multiplied by the correction factor of 1.1.

PREDICTION OF MAXIMAL OXYGEN UPTAKE FROM THE ASTRAND RYHMING NOMOGRAM

Male Subjects

Working Pulse	Predicted Maximal Oxygen Uptake (l/min) 600 kpm/min	900 kpm/min	Working Pulse	Predicted Maximal Oxygen Uptake (l/min) 600 kpm/min	900 kpm/min
120	3.50	4.80	146	2.40	3.30
121	3.45	4.70	147	2.38	3.28
122	3.40	4.62	148	2.35	3.24
123	3.35	4.60	149	2.33	3.20
124	3.30	4.54	150	2.30	3.15
125	3.20	4.43	151	2.28	3.12
126	3.18	4.35	152	2.25	3.08
127	3.14	4.30	153	2.22	3.04
128	3.10	4.20	154	2.20	3.00
129	3.04	4.15	155	2.18	2.98
130	3.00	4.10	156	2.15	2.94
131	2.94	4.04	157	2.13	2.90
132	2.90	4.00	158	2.11	2.88
133	2.84	3.94	159	2.10	2.84
134	2.80	2.90	160	2.08	2.82
135	2.78	3.84	161	2.04	2.80
136	2.74	3.78	162	2.02	2.78
137	2.70	3.70	163	2.00	2.75
138	2.68	3.65	164	1.99	2.70
139	2.65	3.60	165	1.98	2.68
140	2.62	2.55	166	1.94	2.65
141	2.60	3.52	167	1.92	2.62
142	2.54	3.48	168	1.90	2.60
143	2.51	3.42	169	1.88	2.58
144	2.50	3.39	170	1.84	2.55
145	2.44	3.35			

Male Subjects

No.	Subject	Age (Yrs)	height (in.)	weight (kg) subMax test	weight (kg) max test	testing order	pre exercise pulse rate SM test	pre exercise pulse rate MaxTest	tested in Exp.II
1	BF	15	69	65.77	67.58	m-sm	71	74	no
2	SA	15	71	61.92	60.78	sm-m	104	107	no
3	LE	15	67	64.64	64.64	m-sm	69	56	yes
4	SM	15	67.5	58.74	58.29	sm-m	94	72	yes
5	WL	16	63	41.96	41.73	m-sm	81	76	yes
6	DB	16	67.5	63.28	63.73	m-sm	80	96	yes
7	DB	16	69	73.03	72.12	sm-m	64	62	yes
8	TF	16	71.5	70.76	70.76	m-sm	74	68	yes
9	SL	16	66	55.79	55.34	sm-m	-	82	yes
10	LF	16	67	79.83	79.83	sm-m	78	95	yes
11	SW	16	65	64.86	64.86	sm-m	81	74	yes
12	VH	16	68.5	59.87	59.87	sm-m	58	60	yes
13	JS	16	70	59.65	60.78	sm-m	76	67	no
14	LC	16	71	71.67	72.57	m-sm	65	72	no
15	KS	17	66.5	58.51	57.51	m-sm	66	77	yes
16	BJ	17	71	62.37	62.60	sm-m	107	87	no
17	NF	17	69	73.94	73.94	m-sm	63	72	yes
18	BB	17	71	63.50	63.50	m-sm	76	80	yes
19	RC	17	70.5	62.37	62.60	m-sm	88	90	yes
20	TB	17	74	65.32	64.86	m-sm	83	82	no
21	TF	17	70	63.16	62.26	sm-m	76	70	no
22	KM	17	65.5	53.52	53.07	sm-m	64	68	yes
23	SF	17	65.5	75.75	75.98	m-sm	79	82	yes
24	RB	17	69	78.47	79.83	m-sm	81	89	yes
25	TP	17	72.5	60.78	60.33	sm-m	83	75	yes
26	BB	17	64.5	55.34	55.34	sm-m	102	86	no
27	GM	17	67.5	58.51	58.97	m-sm	102	104	yes
28	KC	18	66	72.69	73.26	m-sm	75	74	yes
29	JG	19	70	61.23	60.33	sm-m	69	118	yes

Female Subjects

No.	Subject	Age (Yrs)	height (in.)	weight (kg) subMax test	weight (kg) max test	testing order	pre exercise pulse rate SM test	pre exercise pulse rate MaxTest	tested in Exp.II
31	LB	14	66.5	64.86	63.32	sm-m	110	110	no
32	MM	14	62.5	55.43	54.88	m-sm	84	92	no
33	JM	15	66.5	69.63	69.85	sm-m	103	99	no
34	BO	15	62.5	53.98	54.43	m-sm	94	102	yes
35	CW	15	64	48.08	48.53	m-sm	105	101	yes
36	KS	15	65.5	68.15	68.15	sm-m	86	81	no
37	MP	15	62.5	51.71	51.71	sm-m	86	74	yes
38	HE	15	66.5	57.15	56.70	m-sm	103	86	no

No.	Subjects	Age	height	weight(kg) subMax test	max test	testing order	pre exercise pulse rate SM test	Maxtest	tested in Exp.II
39	SI	16	66.5	57.15	56.25	sm-m	70	72	yes
40	AB	16	66.5	62.14	62.14	m-sm	87	103	yes
41	CA	16	65.5	59.42	58.06	sm-m	-	72	yes
42	BT	16	64.5	59.42	59.42	m-sm	106	105	yes
43	HM	16	63.5	54.43	55.24	sm-m	92	106	yes
44	LI	16	63.5	58.29	59.19	m-sm	76	82	no
45	LN	16	65	60.56	61.92	sm-m	94	97	yes
46	LW	17	68	66.22	66.69	m-sm	99	114	yes
47	CG	17	58	47.63	47.13	sm-sm	70	67	yes
48	JR	17	63.5	50.35	49.44	m-sm	96	103	yes
49	ME	17	64	48.99	48.99	sm-m	95	85	no
50	CM	17	62.5	72.12	72.57	m-sm	70	80	yes
51	KB	17	62.5	52.16	53.07	m-sm	108	119	yes
52	LA	17	63.5	59.42	58.51	m-sm	87	81	yes
53	IK	17	62	51.47	50.35	sm-m	75	77	yes
54	GL	17	64.5	58.06	58.06	sm-sm	84	83	yes
55	GD	17	65	64.41	64.41	sm-m	104	91	yes
56	JC	18	64	70.31	68.49	sm-m	80	88	yes
57	DW	18	65.5	72.57	72.57	sm-sm	96	94	yes

EXPERIMENT I RAW SCORES - MAXIMAL OXYGEN CONSUMPTION

Male Subjects

Subject No.	PREDICTED TEST: Steady state heart rate	Work Load (kpm)	Pred. Max. Oxygen Intake 1/min	Pred. Max. Oxygen Intake ml/kg/min	ACTUAL TEST: Actual Oxygen 1/min	Maximal Intake ml/kg/min	Steady state heart rate	Work load (kpm)	Pred. Oxygen 1/min	Maximal Intake ml/kg/min
1	126.5	600	3.48	52.86	3.70	54.71	124.5	600	3.58	52.90
2	157	600	2.34	37.84	3.15	51.76	158	600	2.32	38.19
3	144.5	600	2.72	42.03	3.41	52.71	126.5	600	3.48	53.78
4	-	600	-	-	2.85	48.91	156.5	600	2.35	40.38
5	132	300	2.00	47.71	1.93	46.13	-	300	-	-
6	161.5	600	2.23	35.29	2.35	36.86	-	600	-	-
7	125	600	3.52	48.20	3.17	43.93	121	600	3.80	52.62
8	124.5	600	3.58	50.52	3.71	52.37	125.5	600	3.51	49.59
9	153.5	900	3.32	59.54	2.86	51.73	138	600	2.95	53.27
10	142.5	450	2.29	28.66	2.81	35.15	-	600	-	-
11	149	600	2.56	39.51	3.34	51.51	160.5	600	2.27	34.94
12	139	600	2.92	48.69	2.89	48.22	149	600	2.56	42.81
13	135	600	3.06	51.27	2.88	47.37	128.5	600	3.38	55.56
14	141	600	2.86	39.91	3.58	49.35	143	600	2.76	38.05
15	136.5	600	2.99	51.14	2.90	50.71	151.5	600	2.50	43.69
16	153.5	600	2.43	38.97	3.21	51.33	137.5	600	2.96	47.27
17	143	600	2.76	37.35	3.07	41.48	143	600	2.76	37.35
18	131.5	600	3.21	50.58	3.50	55.18	137	600	2.97	46.77
19	150.5	450	2.06	32.98	2.48	39.68	168	600	2.09	33.39
20	143	600	2.76	42.27	3.07	47.27	136	600	3.01	46.46
21	122	600	3.74	59.21	-	-	122	600	3.74	60.07
22	135.5	600	3.04	56.73	3.18	59.92	140	600	2.88	54.31
23	146.5	600	2.63	34.71	3.47	45.60	150	600	2.53	33.30
24	131.5	600	3.21	40.93	3.27	40.95	135.5	600	3.04	38.03
25	157.5	600	2.33	38.37	3.25	53.94	151	600	2.51	41.57
26	143.5	600	2.76	49.90	-	-	140	600	2.88	52.07
27	158	600	2.32	39.67	2.59	43.97	160	600	2.29	38.80
28	137.5	900	4.05	55.69	-	-	143	900	3.76	51.35
29	141.5	600	2.83	46.17	3.11	51.60	-	600	-	-

Female Subjects

	PREDICTED TEST				ACTUAL TEST					
Subject No.	Steady state heart rate	Work load (kpm)	Pred. Max. Oxygen Intake 1/min	Pred. Max. Oxygen Intake ml/kg/min	Actual Oxygen 1/min	Maximal Intake ml/kg/min	Steady state heart rate	Work load (kpm)	Pred. Oxygen 1/min	Maximal Intake ml/kg/min
31	150.5	300	1.67	25.78	1.80	28.46	146.5	300	1.78	28.14
32	143.5	300	1.91	35.17	1.88	34.31	142	300	1.93	35.08
33	151.5	300	1.65	28.69	1.90	27.20	150	300	1.68	24.09
34	148	300	1.76	32.60	2.38	43.74	142.5	300	1.91	35.17
35	164.5	300	1.34	27.91	1.78	36.60	167	300	1.29	26.52
36	128.5	300	2.40	35.19	2.24	32.88	144.5	300	1.85	27.12
37	149	300	1.71	32.97	1.62	31.25	146.5	300	1.78	34.46
38	159	300	1.47	25.80	1.73	30.25	144	300	1.87	32.98
39	141.5	300	1.94	33.88	2.04	36.28	131	300	2.28	40.48
40	146	300	1.79	28.85	2.13	34.26	-	300	-	-
41	166.5	450	1.84	30.92	2.09	36.00	153	450	2.15	36.10
42	-	300	-	-	1.48	24.82	165	300	1.33	22.40
43	141.5	300	1.94	35.57	2.19	39.57	146	300	1.79	32.46
44	130	300	2.31	39.63	1.83	30.87	134	300	2.20	37.17
45	127.5	300	2.45	40.50	2.22	35.89	137	300	2.09	33.75
46	139	300	1.99	30.06	2.00	29.96	138	300	2.04	30.51
47	160	300	1.44	30.25	-	-	163	300	1.38	29.17
48	153.5	300	1.61	31.90	1.74	35.25	152	300	1.65	33.37
49	153	300	1.61	32.78	1.76	35.97	150	300	1.68	34.35
50	135.5	300	2.13	29.59	1.86	25.56	139.5	300	1.99	27.43
51	156	300	1.54	29.52	1.69	31.84	160.5	300	1.42	26.73
52	146	300	1.79	30.17	2.61	44.68	-	300	-	-
53	154.5	300	1.58	30.78	1.58	31.32	147.5	300	1.76	34.96
54	150	300	1.68	28.99	-	-	142.5	300	1.90	32.78
55	139	300	1.99	30.91	2.19	34.06	128.5	300	2.40	37.24
56	126.5	300	2.51	35.67	2.36	34.47	149	300	1.71	24.89
57	149	300	1.71	23.50	-	-	141	300	1.95	26.83

EXPERIMENT II

RAW SCORES OBTAINED ON THE ASTRAND-RYHMING PREDICTED MAXIMAL OXYGEN INTAKE TEST.

Males.

Age 14		15		16		17		18		19		20		21	
1/min	ml/kg/min	1/min	ml/kg/min	1/min	ml/kg/min	1/min	ml/kg/min	1/min	ml/kg/min	1/min	ml/kg/min	1/min	ml/kg/min	1/min	ml/kg/min
2.09	37.16	2.95	52.00	3.47	46.30	2.50	35.07	2.95	34.57	3.56	35.88	3.37	61.34	3.19	42.63
2.16	40.28	2.11	34.75	2.07	38.64	3.10	33.53	3.19	45.13	3.66	42.06	3.28	41.06		
2.15	51.30	3.72	56.53	1.87	35.54	2.85	39.50	2.85	45.19	3.30	54.30	2.09	31.57		
2.32	34.57	2.94	37.86	3.26	45.13	3.05	41.47	4.05	43.32	3.00	41.12	3.21	48.51		
3.19	48.50	2.83	38.71	2.85	44.23	3.54	51.37	3.28	50.18	2.19	35.49				
2.09	35.72	2.56	42.48	3.05	45.39	2.96	38.78	2.20	27.40	2.53	35.30				
		2.30	39.91	3.56	49.12	3.23	42.69	2.19	36.56	3.32	57.22				
		1.41	28.74	3.27	38.64	2.34	39.14	2.32	34.11	3.12	52.98				
		2.48	60.63	3.29	51.80	2.88	44.75	2.94	43.75	2.18	35.84				
		2.83	45.16	3.66	57.68	3.45	55.18	2.88	48.87	2.23	35.67				
		3.28	50.90	3.52	67.49	2.24	41.23	2.27	31.42	2.16	38.32				
		2.81	45.47	2.19	36.84	3.30	49.48	3.00	50.16	2.43	44.30				
		2.88	47.07	2.95	50.78	3.09	44.25	2.97	37.63	3.61	55.23				
		2.84	45.01	3.50	50.40	3.18	56.07	2.68	46.59	4.42	58.04				
		2.55	40.19	2.41	31.80	2.95	44.83	2.33	33.83	2.52	45.16				
		3.50	51.07	2.92	38.71	3.17	54.99	2.55	34.52	3.56	45.42				
		3.50	44.58	2.81	44.18	2.24	34.12	2.72	44.70	3.06	41.36				
		2.32	39.67	2.92	45.57	2.81	34.35	2.29	33.19	2.52	37.52				
		3.03	45.68	2.44	36.14	2.22	38.89	2.57	39.69	2.97	38.97				
		3.39	70.47	2.44	39.59	2.94	46.59	2.40	34.11	3.52	48.81				
		3.26	58.84	2.81	44.18	2.41	44.26	3.05	47.98	2.95	43.33				
		2.92	42.85	2.29	34.55	3.28	45.74	2.18	40.02	3.52	52.78				
		2.22	41.51	2.20	38.80	2.95	47.44	3.29	45.03	2.79	45.97				
		3.87	60.12	3.06	45.86	2.59	45.23	3.03	44.76	2.34	46.12				
		3.21	44.81	3.07	43.10	3.63	48.50	3.69	62.02	2.20	39.75				
		3.21	64.97	4.42	62.10	3.03	41.68	2.96	49.05	3.00	48.32				
		1.96	42.32	2.94	49.42	3.39	43.68	2.22	43.35	2.78	42.32				
		2.44	44.87	2.66	38.36	3.34	44.14	4.33	56.88	2.83	29.13				
		2.41	41.17	3.28	57.35	1.41	27.23	2.92	39.42	3.08	44.10				
		2.23	34.43	2.75	52.26	3.11	40.61	2.30	33.79	3.08	44.67				
		2.19	34.22	2.94	44.04	2.87	47.23	2.53	37.94	2.23	35.17				
		2.34	46.96	2.66	43.47	3.94	61.57	2.87	41.37	2.35	30.89				
		3.03	41.43	2.30	31.28	3.12	44.15	3.61	47.92	2.90	49.25				
		2.87	46.20	2.11	37.85	3.56	43.18	4.29	46.82	2.86	43.48				
		3.21	46.89	3.63	61.56	2.56	34.88	4.22	52.32	3.41	53.70				
		3.99	52.40	2.59	47.49	3.04	37.39	2.64	45.47	2.44	27.61				

EXPERIMENT II RAW SCORES OBTAINED ON THE ASTRAND-RYHMING PREDICTED MAXIMAL OXYGEN INTAKE TEST.

Males

Age 14		15		16		17		18		19		20	
1/min	ml/kg/min	1/min	ml/kg/min	1/min	ml/kg/min	1/min	ml/kg/min	1/min	ml/kg/min	1/min	ml/kg/min	1/min	ml/kg/min
		2.40	46.38	2.48	46.64	2.62	38.48	2.95	44.21				
		2.88	58.83	3.37	37.66	2.90	46.39	2.97	45.16				
		1.86	37.60	3.23	57.04	3.71	49.83	3.75	75.87				
		2.68	42.88	3.59	55.67	3.50	52.11	2.62	43.73				
		3.59	54.53	2.72	57.05	3.81	51.80	2.97	47.10				
		2.92	50.20	3.34	49.15	3.17	48.50	2.75	41.28				
		3.27	53.75	3.63	65.59	2.56	39.24	3.43	47.29				
		3.38	63.10	3.94	57.11	2.05	34.97	3.07	40.76				
		2.37	48.73	2.72	41.32	4.68	54.53	3.25	57.23				
		3.08	53.46	2.76	47.19	3.17	40.60	3.47	55.35				
		1.87	43.40	1.43	32.85	2.33	36.98	3.61	60.72				
		2.46	47.23	2.39	40.48	2.05	33.91	3.52	55.03				
		3.18	56.07	2.64	44.77	2.99	36.64	3.04	49.59				
		2.94	49.06	2.21	28.68	2.59	36.53	3.83	55.15				
		2.95	53.27	2.32	29.24	2.20	40.41	3.05	48.16				
		3.27	53.75	2.44	41.42	3.59	56.87	2.51	36.86				
		2.46	47.23	2.44	43.07	2.18	32.66	2.99	46.45				
		3.12	49.19	3.41	43.46	3.63	54.08	2.50	42.68				
		1.65	29.11	3.71	58.80	3.26	52.39	2.75	45.94				
		2.95	49.61	3.91	57.78	3.15	52.94	2.39	33.10				
		3.30	61.66	2.43	32.09	2.62	39.26	3.61	48.21				
		2.39	33.52	2.18	39.69	4.05	51.59	2.92	49.34				
		3.69	46.70	2.86	45.03	3.08	42.70	3.41	40.41				
				2.35	34.60	1.65	36.23	2.75	50.11				
				2.79	48.13	2.29	40.07	2.83	38.95				
				2.78	42.91	2.61	39.37	2.51	38.67				
				2.90	45.73	2.66	50.59	3.59	41.17				
				2.23	34.19	2.62	46.54	2.53	46.10				
				2.41	54.47	3.21	40.93	4.60	56.00				
				2.56	36.70	2.61	40.76	2.83	34.24				
				2.55	29.93	2.72	35.23	3.52	45.39				
				2.52	37.03	2.86	46.71	3.89	56.86				
				3.03	39.70	2.32	32.38	4.26	57.94				
				2.53	42.58	3.12	43.04	4.33	57.92				
				3.12	47.18	3.12	49.54	3.07	49.75				
				2.78	49.48	2.40	44.43	3.06	44.95				
				3.85	54.41	3.50	64.26	2.29	38.21				

Age 14		15		16		17		18		19		20	
l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min
				3.10	47.83	2.94	37.86	4.07	45.55				
				3.30	45.47	3.58	65.68	3.07	36.38				
				3.12	46.85	2.16	32.56	3.54	42.91				
				3.52	52.78	2.40	58.75	2.87	39.81				
				3.41	57.83	2.76	44.43	3.61	60.27				
				3.12	48.50	2.55	43.96	3.85	42.23				
				2.94	44.66	2.83	43.89	2.22	36.29				
				3.23	59.41	3.07	60.41	3.15	37.49				
				2.76	49.90	3.76	53.86	3.01	47.81				
				3.52	53.15	2.63	44.94	3.09	45.75				
				2.63	56.28	3.52	54.27						
				3.94	61.14	2.56	46.71						
				3.73	41.11	2.18	33.34						
				3.85	58.94	3.12	50.64						
				2.55	34.52	3.19	48.17						
				3.21	51.32	2.34	29.35						
				3.06	56.18	2.24	34.60						
				3.28	55.58	2.43	33.09						
				2.97	48.86	2.83	51.94						
				3.26	49.85	2.44	36.62						
				3.38	30.61	2.95	41.13						
				2.96	47.27	2.24	35.34						
				2.78	23.35	2.35	37.88						
				2.68	38.68	2.57	42.35						
				2.56	43.46	3.69	52.07						
				2.97	51.15	2.63	46.00						
				4.02	63.23	2.20	36.75						
				2.59	41.90	2.97	-						
				3.04	49.95	5.06	69.29						
				2.53	43.24	2.29	36.55						
				3.91	61.93	2.68	32.52						
				2.37	33.42	4.07	50.13						
				2.48	35.89	4.19	59.61						
				2.90	44.77	2.32	34.57						
				2.20	44.10	3.30	49.48						
				2.97	53.67	2.94	49.42						
				3.91	64.25	2.66	51.04						
				2.87	52.74	2.95	38.69						
				2.37	44.56	3.44	61.20						
				3.69	55.65	4.29	71.65						
				2.53	39.01	4.37	65.95						

Males

Age 14		15		16		17		18		19		20	
l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min
				3.63	52.31	2.66	35.77						
				2.22	31.00	3.28	34.88						
				2.30	39.91	3.74	62.00						
				2.88	44.43	2.46	45.27						
				2.88	34.34	2.41	34.05						
				3.08	49.20	2.56	36.70						
				2.68	48.11	3.04	40.57						
				4.35	61.40	2.64	40.14						
				4.02	57.85	2.87	43.55						
				2.34	30.38	2.57	36.61						
				2.07	32.33	2.55	30.58						
				3.21	50.58	2.21	51.32						
				2.22	34.99	3.73	60.45						
				2.30	28.96	2.59	44.18						
				3.07	57.83	4.27	61.50						
				2.52	37.03	3.69	66.58						
				2.78	39.33	3.61	39.78						
				2.75	42.10	3.09	54.96						
				2.34	36.89	2.16	34.20						
				2.87	54.10	3.62	57.40						
				3.94	54.60	2.64	43.12						
				2.52	44.08	2.68	43.20						
				3.47	48.66	3.52	53.15						
				3.99	50.30	3.99	59.08						
				2.59	46.33	3.01	54.92						
				4.37	55.97	2.23	45.58						
				2.29	50.24	2.64	32.58						
				2.72	47.16	2.87	39.57						
				2.29	42.03	2.59	44.18						
				3.01	55.37	4.05	57.95						
				3.37	50.14	3.80	56.16						
				2.44	41.73	2.76	47.19						
						4.26	73.90						
						4.22	58.56						
						4.48	54.23						
						2.88	44.43						
						2.66	34.12						
						2.76	46.82						
						3.75	51.36						

Males

Age 14		15		16		17		18		19		20	
l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min
						2.50	35.52						
						3.07	48.33						
						2.83	46.51						
						2.51	39.50						
						2.92	53.12						
						3.87	53.69						
						2.76	60.63						
						2.95	47.44						
						3.76	54.56						

EXPERIMENT II

RAW SCORES OBTAINED ON THE ASTRAND-RYHMING PREDICTED MAXIMAL OXYGEN INTAKE TEST.

Females

Age 14		15		16		17		18		19		20		21	
l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min
1.51	33.90	1.77	29.36	2.63	41.11	2.55	31.09	2.90	50.81	1.91	25.73	1.95	35.77	1.67	36.72
2.70	45.01	2.12	33.91	2.08	35.81	2.04	32.51	2.61	42.58	2.60	57.00	2.31	36.38		
1.43	25.84	1.43	31.41	2.12	34.67	1.76	31.04	1.24	30.79	1.27	23.24				
1.95	34.90	2.27	37.85	2.02	34.32	1.87	31.71	2.72	47.92	2.20	46.19				
		1.95	38.32	2.28	35.10	2.12	29.44	1.47	29.75	2.02	36.58				
		1.97	37.75	2.22	37.68	2.05	46.02	1.89	27.26	2.89	52.27				
		2.64	56.01	1.91	32.71	1.89	35.35	2.45	42.92	1.65	39.55				
		3.05	44.19	2.18	41.39	2.57	50.22	2.97	41.18						
		2.75	50.11	1.87	37.33	1.31	25.99	1.63	27.40	3.29	48.66				
		1.44	32.09	1.49	30.60	2.53	35.30	1.93	35.37	1.53	24.42				
		1.56	23.42	1.77	35.18	1.95	45.19	2.42	45.60						
		2.06	39.44	2.40	25.18	2.43	40.91	1.44	32.42						
		1.56	26.29	2.02	39.84	2.39	54.82	1.28	21.64						
		1.84	38.97	2.04	36.48	1.36	27.09	1.79	28.44						
		1.43	27.41	1.76	36.27	2.17	43.04	1.68	29.92						
		1.49	30.32	1.93	36.91	1.27	26.84	1.76	35.28						
		1.33	26.68	1.74	27.37	2.52	45.52	2.51	44.58						
		2.12	38.05	1.79	31.63	1.68	33.43	1.91	33.22						
		1.89	31.60	1.65	33.37	2.10	44.99	2.23	40.03						
		2.20	37.03	2.27	35.68	2.63	43.91	2.01	42.71						
		2.11	34.50	2.13	45.28	2.20	38.19	1.60	33.63						
		1.49	26.19	1.99	32.52	1.42	31.16	2.51	32.34						
		1.25	35.00	1.95	37.65	2.11	44.81	2.04	30.11						
		1.65	29.82	2.42	38.65	1.78	27.48	2.19	34.72						
		1.89	35.35	1.91	32.71	1.82	36.05	1.95	37.65						
		1.41	26.99	1.76	28.33	1.32	24.26	3.43	48.81						
		1.55	32.26	1.88	31.90	2.33	36.73	1.96	36.28						
		1.49	26.19	1.31	28.74	1.46	25.71	1.61	30.26						
		2.28	49.71	2.02	41.32	1.54	33.62	2.01	48.76						

EXPERIMENT II

<u>Females</u>

Age 14		15		16		17		18		19		20	
l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min
		1.89	33.37	2.15	39.73	1.95	33.02	2.19	40.22				
		3.14	58.08	2.20	34.89	2.57	35.46	2.00	31.31				
		2.41	39.67	1.89	35.73	1.87	35.85	1.49	22.46				
		2.10	40.63	1.89	43.45	2.04	37.70	1.89	33.36				
		3.17	53.72	1.87	33.79	2.34	41.66	1.88	30.05				
		1.89	29.80	1.87	37.14	2.35	37.88	2.41	42.82				
		2.33	36.73	1.36	27.84	2.02	34.32	2.75	48.84				
		1.95	42.50	2.67	44.65	1.86	33.87	2.11	34.23				
		1.98	36.38	2.45	43.97	1.33	24.66	1.93	36.28				
		2.28	36.64	2.12	37.44	2.39	40.17	2.89	46.66				
		1.93	38.59	1.56	27.34	2.28	41.15						
		1.61	31.90	1.44	29.41	2.10	43.30						
		1.43	32.18	1.97	42.14	2.19	37.43						
		2.30	41.55	1.97	36.48	2.97	61.78						
		1.29	28.15	1.28	24.89	1.98	39.69						
		1.87	37.83	2.28	46.48	1.93	40.41						
		1.89	27.81	2.48	47.86	1.93	32.90						
		1.99	41.42	1.98	39.33	2.06	40.13						
		2.67	49.10	2.17	41.18	2.40	40.05						
		2.06	43.65	2.34	43.04	1.99	32.76						
		1.88	31.66	2.57	45.40	1.67	37.24						
		1.54	30.59	2.42	50.81	1.93	39.29						
		2.06	43.19	2.92	43.42	1.65	30.57						
		2.31	48.05	1.93	33.68	2.17	39.49						
		1.80	40.17	1.93	32.15	1.84	33.47						
		1.99	39.55	2.40	43.33	1.77	25.36						
		1.56	29.69	2.19	35.22	1.78	25.51						
		1.93	38.59	2.28	40.16	2.94	46.92						
				2.10	31.09	1.77	36.50						

EXPERIMENT II

Females

Age	14	15		16		17		18		19		20	
l/min	ml/kg/ min	l/min	ml/kg/ min	l/min	ml/kg/ min	l/min	ml/kg/ min	l/min	ml/kg/ min	l/min	ml/kg/ min	l/min	ml/kg/ min
		1.51	34.62	2.51	40.06	1.91	41.78						
		1.74	42.02	1.93	39.67	2.18	47.54						
		2.39	38.98	1.24	26.86	2.55	43.62						
		2.09	38.40	1.95	34.34	1.77	32.00						
		1.76	40.84	2.86	52.55	1.69	30.87						
		2.35	48.05	2.34	40.04	2.11	35.54						
		1.88	34.28	2.60	44.36	2.57	41.12						
		2.64	45.47	1.79	35.94	1.97	47.70						
		2.20	37.03	1.87	32.21	2.52	44.78						
		1.36	25.06	2.09	43.07	2.29	47.14						
		1.94	35.57	1.76	28.53	2.08	41.29						
		1.61	30.53	2.75	36.09	1.98	32.34						
		1.77	29.58	2.40	48.07	1.89	40.89						
		2.39	44.22	2.37	48.28	1.95	40.88						
		1.47	30.09	1.95	33.28	2.75	39.12						
		1.78	29.77	1.35	26.17	1.91	36.70						
		1.93	37.22	1.42	22.34	2.97	48.51						
		2.84	35.55	2.39	38.98	2.94	43.75						
		2.30	40.23	2.01	43.51	1.65	30.32						
		2.00	36.48	1.85	33.67	2.17	40.49						
		2.28	34.86	1.88	32.91	1.89	37.58						
		2.12	31.21	1.89	32.34	1.65	33.08						
				1.58	29.60	1.58	31.75						
				1.95	32.03								
				1.65	33.08								
				1.99	37.84	1.55	37.58						
				2.40	48.07	1.56	31.02						
				1.93	38.59	1.77	32.54						
				1.88	31.90	1.71	25.56						
				1.58	36.38	1.68	34.05						
				2.15	39.41	2.78	49.48						
				2.04	34.51	2.89	58.52						

[illegible]

EXPERIMENT II

Females

Age 14		15		16		17		18		19		20	
l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min
				1.88	38.40								
				1.44	24.07	2.18	48.99						
				2.11	40.84	2.67	48.30						
				2.48	48.72	1.94	42.52						
				2.20	42.55	2.01	35.22						
				1.67	32.05	1.63	34.54						
				1.61	29.26	1.74	30.17						
				2.52	40.24	2.33	41.13						
				1.87	29.45	2.75	55.12						
				1.93	35.97	2.24	39.58						
				1.98	34.93	1.91	30.80						
				2.63	39.97	2.18	36.65						
				2.02	35.70	1.44	32.09						
				1.93	38.24	1.77	35.50						
				1.93	41.60	2.53	42.90						
				2.04	41.16	2.28	45.64						
				2.06	38.10	2.70	49.51						
				1.84	36.82	1.49	30.04						
				1.93	40.04	2.50	44.04						
				1.53	25.54	2.11	29.11						
				1.61	34.71	2.34	42.34						
				2.64	40.14	2.34	42.34						
				2.89	51.44	2.35	40.55						
				1.28	21.15	2.12	33.43						
				1.58	24.60	2.19	37.13						
				1.43	28.67	1.94	41.07						
				2.48	41.97	1.77	37.91						
				1.73	40.08	2.99	48.86						
				2.15	37.83	2.17	41.55						
				1.42	30.67	2.64	52.44						
				2.20	37.31	2.35	39.92						
				1.31	26.48	1.89	37.58						

EXPERIMENT II

<u>Females</u>

Age 14		15		16		17		18		19		20	
1/min	ml/kg/min	1/min	ml/kg/min	1/min	ml/kg/min	1/min	ml/kg/min	1/min	ml/kg/min	1/min	ml/kg/min	1/min	ml/kg/min
				1.88	39.13	2.33	43.57						
				1.88	37.03	2.11	41.58						
				2.41	37.40	2.01	38.93						
				2.28	41.49	2.28	34.62						
				1.93	33.68	3.05	41.47						
				1.98	27.46	1.79	31.12						
				2.04	29.51	2.13	38.89						
				2.48	41.97	1.95	35.77						
				1.99	29.07	2.75	50.94						
				2.41	54.76	2.01	35.51						
				2.01	38.93	2.31	43.53						
				1.98	36.38	2.34	36.12						
				2.15	38.45								
				1.27	30.99								
				2.97	52.38								
				1.58	31.46								
				1.71	27.23								
				2.04	27.19								
				2.53	44.98								
				1.97	43.85								
				1.93	38.94								
				1.69	33.34								
				2.27	34.45								
				2.51	44.58								
				1.89	34.19								
				3.10	62.17								
				2.37	43.45								
				2.78	59.05								
				2.06	44.45								
				1.87	31.71								

APPENDIX D

CORRECTION FACTORS

CORRECTIONS FOR THE BECKMAN E-2 OXYGEN ANALYZER.

The accuracy of this instrument was tested against two micro-Scholander instruments operated by laboratory technicians in the Cardio-pulmonary Laboratory at the University of Alberta and laboratory of the Department of Physiology at the University of Alberta.

The values obtained with the two Scholanders were averaged and a regression equation based on the Beckman reading and Scholander values was calculated. This equation was found to be:

$$Y^1 = .893\ X + 2.22$$

where Y^1 = corrected percentage of oxygen

and X = percentage of oxygen as read on the Beckman E-2 analyzer.

The discrepancy was found to be due to impure nitrogen which was used as a calibration gas (18,39).

In Experiment I, this correction factor was employed on some of the oxygen determinations and not on others. In the latter case a second cylinder of nitrogen, which was found to be pure when tested, was used as the calibration gas.

CORRECTIONS FOR AMERICAN METER CO. GAS METER #802.

This meter was tested for its volume determinations using as standards the large Tissot tank in the Faculty of Physical Education Laboratory and a smaller Tissot in the Cardio-pulmonary Laboratory at the University of Alberta Hospital. It was found to be recording volume readings in excess of actual volumes pumped, as indicated by the Tissot tanks. A second American Meter Co. gas meter, in use in the University Hospital was found to give extremely accurate readings when compared to the same Tissot tanks.

The data collected was analyzed and a regression equation calculated. This equation was found to be:

$$Y = .22770 + .943099\ X$$

where X = corrected volume

Y = volume as read on American Meter Co. Meter#802.

This regression equation was then used to calculate a complete set of correction tables. These tables also incorporate a factor of loss of volume during oxygen and carbon dioxide analysis, with the factor being considered as 300 cc for each reading. (18,39).

CORRECTION FOR PALPATION HEART RATES.

Heart rates obtained by the palpation method were found to be in error when compared with 24-30 beat complexes obtained from the electrocardiograph.

Regression lines for each of the three investigators were constructed on the basis of the electrocardiograph values. The equations were found to be:

Investigator	Regression Lines.
H.G.	$Y = 1.067\,X - 4.42$
R.N.	$Y = 1.001\,X + 5.42$
R.H.	$Y = 1.036\,X - 2.71$